Issued February 20, 1913.

U. S. DEPARTMENT OF AGRICULTURE,

OFFICE OF PUBLIC ROADS—BULLETIN NO. 45.

LOGAN WALLER PAGE, DIRECTOR.

DATA FOR USE IN DESIGNING CULVERTS AND SHORT-SPAN BRIDGES.

BY

CHARLES H. MOOREFIELD,
Highway Engineer, Office of Public Roads.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1913.

OFFICE OF PUBLIC ROADS.

REINFORCED CONCRETE CULVERT ON MASSACHUSETTS STATE ROAD.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Public Roads,
Washington, D. C., November 5, 1912.

Sir: I have the honor to transmit herewith a manuscript which purposes to furnish data for use in designing and constructing highway culverts and short-span masonry bridges. These data have been prepared in response to a general public demand, and in furtherance of a plan outlined in Bulletin No. 43 of this office.

The work of computing the tables and preparing the drawings was performed largely by Messrs. E. J. Ducey, W. J. R. Weir, M. E. Worrell, and H. K. Craig, junior highway engineers in the Office of Public Roads, under the supervision of Mr. Charles H. Moorefield, highway engineer of this office, who prepared the text.

I respectfully recommend that this manuscript be published as Bulletin 45 of this office.

Respectfully,

Paul D. Sargent,
Acting Director.

Hon. James Wilson,
Secretary of Agriculture.

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DATA FOR USE IN DESIGNING CULVERTS AND SHORT-SPAN BRIDGES.

INTRODUCTION.

This paper purposes to supply suggestions and preliminary data for use in designing highway culverts and short-span masonry bridges. The proper design and erection of such structures, however, involves the exercise of judgment and skill, which is to be acquired only through training and experience. The intelligent use of the data herein presented must, therefore, necessarily be limited to engineers and experienced foremen.

Almost every drainage problem presents some peculiar feature which requires special treatment to be worked out on the ground, and no treatise, however detailed, can take the place of a competent engineer. It is, therefore, assumed in this paper that the reader is already familiar with the various methods of designing and constructing small drainage structures for highways, and very little effort has been made to prescribe definite methods of procedure for individual cases. The data given usually deal separately with the various parts of a structure, such as the floor, beams, wing walls, abutments, etc., and the assembling of these parts is left to the discretion of the designer. A few complete designs, typical of common practice, are shown, however.

Most of the tables which follow have been computed especially for this paper, but, wherever practicable, they have been compared with others of similar character. The assumptions under which the computations have been made always lean well to the side of safety.

AREA OF WATERWAY.

The size of the opening or area of waterway, as it is ordinarily termed, which should be provided for a bridge or culvert depends on a number of conditions, which are more or less uncertain and can not therefore be determined with any very considerable degree of exactness.

The principal factors which should be considered in determining the area of waterway are: (1) The maximum rate of rainfall and the maximum duration of time over which it continues; (2) the character, inclination, and shape of the surface which it is proposed to drain; (3) the condition and inclination of the bed of the stream; (4) the

shape and inclination of the culvert; and (5) whether it is permissible to have the culvert discharge under a head.

The determination of values for most of these factors is evidently largely a matter of judgment and must be liable to considerable error.

A number of formulæ have been suggested which give directly the relation between the area of waterway required and the surface area to be drained. Table 1 has been prepared from Prof. A. N. Talbot's formula, area of waterway in square feet $= C\sqrt[4]{(\text{drainage area in acres})^3}$, in which C is a constant depending on the slope. The values given are intended only as aids to the judgment, and care should be exercised in their application.

TABLE 1.—*Relation between area drained and area of waterway.*

Area drained.	Area of waterway in square feet.			Area drained.	Area of waterway in square feet.		
	Abrupt slopes.	Rolling agricultural country.	Level country.		Abrupt slopes.	Rolling agricultural country.	Level country.
Acres.	$C=1$	$C=\frac{1}{3}$	$C=\frac{1}{5}$	*Acres.*	$C=1$	$C=\frac{1}{3}$	$C=\frac{1}{5}$
1	1.00	0.33	0.20	60	21.58	7.19	4.31
2	1.68	.56	.33	70	24.20	8.06	4.84
3	2.27	.75	.45	80	26.76	8.92	5.35
4	2.83	.94	.56	90	29.24	9.74	5.84
5	3.33	1.11	.66	100	31.62	10.54	6.32
6	3.83	1.27	.76	125	37.40	12.46	7.48
7	4.30	1.43	.86	150	42.85	14.28	8.57
8	4.75	1.58	.95	175	48.22	16.07	9.64
9	5.19	1.73	1.03	200	53.20	17.73	10.64
10	5.61	1.87	1.12	250	63.05	21.01	12.61
12	6.43	2.14	1.28	300	72.18	24.06	14.53
14	7.23	2.41	1.44	400	89.44	29.81	19.88
16	7.98	2.66	1.59	500	105.74	35.25	21.15
18	8.72	2.90	1.74	750	143.30	47.76	28.66
20	9.42	3.14	1.88	1,000	177.80	59.26	35.56
25	11.18	3.72	2.23	1,500	241.00	80.33	48.20
30	12.83	4.27	2.56	2,000	299.60	99.86	59.92
35	14.40	4.80	2.88	3,000	405.30	135.10	81.06
40	15.92	5.30	3.18	4,000	504.00	168.00	100.80
45	17.35	5.78	3.47	5,000	595.00	198.33	119.00
50	18.82	6.27	3.76	10,000	1,000.00	333.33	200.00

Valuable data for use in determining the proper area of waterway for any particular location may also be obtained by observing existing openings on the same stream or by measuring its cross-section at times of high water. The height of high water may be approximately determined from drift, or from the testimony of local residents, or both.

Provision should be made for all ordinary floods with a moderate margin of safety. It is not usually considered economical, however, to provide for extreme conditions, such as have been known to occur in nearly every community perhaps once or twice within the recollection of the oldest inhabitants.

If the additional cost required to take care of an extreme contingency likely to occur only once in a given number of years would amount, when capitalized at a reasonable rate of compound interest for the same period, to more than the cost of replacing the structure

which might be destroyed or damaged, the advisability of making the increased expenditure is questionable, and, unless considerations of human safety or probable inconvenience enter in, it should not be incurred.

MATERIALS FOR CULVERTS.

Culverts are built of various materials, such as stone, brick, concrete, and pipe of cement, vitrified clay, cast iron, or corrugated metal. Wood is also frequently used, but, on account of the high cost of maintenance and the inconvenience and discomforts attending periodic repairs or renewals, it is a very undesirable material, and its use should be avoided.

Pipe culverts are well adapted for places where a comparatively small area of waterway is required. Up to 24 inches in diameter they are usually economical and are easily handled and laid. When a greater diameter than 24 inches is required, it is well to compare the cost with that of a box culvert of equivalent sectional area. The practice in vogue with some engineers of employing two parallel lines of pipe when one is insufficient for carrying the water is not to be recommended. It is seldom economical and the waterway is much more liable to become obstructed by floating débris than where a single opening is used.

Box culverts ranging in span from 1 to 5 feet may be built of stone or reinforced concrete, or a combination of the two. Brick may also be used in combination with one of these. Its monolithic form gives reinforced concrete a decided advantage over either stone or brick, but considerations of economy sometimes justify the use of one of the latter materials. For spans greater than 5 feet it is impractical to use stone for a flat top. Flat superstructures of reinforced concrete have been economically used, however, for spans up to 50 feet.

VITRIFIED-CLAY PIPE.

Vitrified-clay culvert pipe should be double strength, hard burned, and salt glazed. Each pipe should be a true cylinder; it should be free from cracks and should have a thickness of shell of at least one-twelfth of the internal diameter.

Table 2 gives approximate dimensions and price of vitrified-clay pipe and the amount contained in a carload.

TABLE 2.—*Approximate dimensions, weight, and cost of vitrified-clay culvert pipe.*

Inside diameter	Cross-sectional area.	Thickness of shell.	Depth of socket.	Length of pipe.	Weight per foot.	List price [1] per foot.	Carload.
Inches.	*Sq. ft.*	*Inches.*	*Inches.*	*Feet.*	*Pounds.*		*Feet.*
10	0.54	$\frac{7}{8}$	$2\frac{3}{4}$	$2\frac{1}{2}$	32	\$0.65	900
12	.78	1	3	$2\frac{1}{2}$	50	.85	600
15	1.23	$1\frac{1}{4}$	3	$2\frac{1}{2}$	70	1.25	400
18	1.76	$1\frac{1}{2}$	$3\frac{1}{2}$	$2\frac{1}{2}$	100	1.70	300
21	2.39	$1\frac{3}{4}$	$3\frac{3}{4}$	$2\frac{1}{2}$	135	2.50	225
24	3.14	2	4	$2\frac{1}{2}$	180	3.25	170

[1] Prices subject to discount of from 65 to 70 per cent f. o. b. factory.

In preparing the ditch the bottom should be rounded out to fit the pipe with suitable depressions for the bells, and the pipe when laid should be true to grade. Where rock is found in the ditch, the bottom should be excavated some 6 inches below the lower surface of the pipe and replaced with clay or sand. The pipe should at no place rest on solid rock.

The laying of the pipe should begin at the downstream end and the bells should point upstream. A small stone wedge should be inserted in the bell of each pipe immediately under the barrel of the succeeding pipe; otherwise slight jogs will result at the joints and afford lodging places for sticks and trash.

The joints should be thoroughly filled with a 1:2 mortar of cement and sand, and all surplus mortar which finds its way through to the inside should be removed.

In backfilling care should be taken that only earth, sand, or other selected material is placed immediately around the pipe, and that this is carefully and thoroughly tamped. In cold climates earth should not be used. Sand, gravel, or broken stone should cover the pipe for at least 6 inches.

The outlet should be excavated to a width and depth sufficient to carry the water away from the end of the culvert quickly. This is of especial importance where freezing is likely to occur.

The top surface of the pipe should be at least 1½ diameters below the surface of the roadway and never less than 18 inches.

Substantial and neatly designed end walls should always be constructed at the ends of a pipe culvert. They serve as a protection to both the culvert and the road, and, since the amount of pipe required is materially lessened by their use, very little is saved by failing to construct them. They may be built of either brick or concrete. Table 3 gives suitable dimensions for each.

TABLE 3.—*Data relating to pipe culvert end walls.*

Diameter of pipe.	End wall dimensions.					Quantities in two end walls.		
	Length.	Height.	Thickness at base.		Size of footing (width × depth).	Concrete.	Brick.	Cement required to lay brick.
			Concrete.	Brick.				
Inches.	*Ft. in.*	*Ft. in.*	*Inches.*	*Inches.*	*Inches.*	*Cu. yds.*	*Number.*	*Bags.*
10	4 6	2 0	10	12	24 by 14	1.3	930	8.9
12	5 0	2 2	10	12	24 by 14	1.5	1,050	9.9
15	6 0	2 6	12	12	24 by 15	2.0	1,350	12.9
18	7 0	2 9	12	12	24 by 15	2.4	1,640	15.6
21	8 0	3 0	16	16	28 by 15	3.3	2,280	21.8
24	9 0	3 4	16	16	28 by 15	3.9	2,730	26.1

Plate II is a typical example of vitrified-clay pipe culverts showing end walls of both concrete and brick.

CAST-IRON PIPE.

Cast-iron pipe culverts are constructed in the same manner as vitrified-clay pipe culverts, and should be provided with similarly designed end walls. Cast-iron pipe may, however, be laid nearer the surface than vitrified-clay pipe, and is not as liable to damage by freezing. It may be obtained in 12-foot lengths, in 3-foot lengths, or in longitudinal sections, which are bolted together in place. Table 4 gives the dimensions and weights of the standard sizes. The lighter weights given under the 12-foot lengths are ordinarily used for culverts.

TABLE 4.—*Sizes, thickness, and weights of cast-iron pipe.*

Inside diameter.	Standard 12-foot lengths.				Standard 3-foot lengths.	
	Light.		Medium.			
	Thickness.	Weight, per foot.[1]	Thickness.	Weight, per foot.[1]	Thickness.	Weight, per foot.[1]
Inches.	*Inch.*	*Pounds.*	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*
12	$\frac{1}{2}$	70	$\frac{33}{64}$	75	$\frac{3}{8}$	60
14	$\frac{9}{16}$	90	$\frac{19}{32}$	100	$\frac{7}{16}$	70
16	$\frac{19}{32}$	100	$\frac{39}{64}$	125	$\frac{1}{2}$	90
18	$\frac{11}{16}$	135	$\frac{47}{64}$	167	$\frac{9}{16}$	105
20	$\frac{41}{64}$	150	$\frac{55}{64}$	200	$\frac{9}{16}$	120
24	$\frac{13}{16}$	200	1	250	$\frac{5}{8}$	160
30	$\frac{13}{16}$	250	$1\frac{1}{16}$	334	$\frac{3}{4}$	220
36	$\frac{7}{8}$	334	$1\frac{1}{8}$	450	$\frac{3}{4}$	300

[1] Weight of bell included.

The price of cast-iron pipe, under ordinary conditions of the market, varies from 1.25 cents to 1.50 cents per pound at the factory. The cost delivered should seldom exceed 2.50 cents per pound.

CORRUGATED-IRON PIPE.

Many culverts are now being constructed of corrugated pipe made of pure iron. The corrugations make the use of relatively very thin metal possible without danger of collapse, and it is claimed that the pure iron of which the pipe is made offers superior resistance to corrosion. As far as is known, these culverts are proving generally satisfactory, but since they have been in use only a comparatively short time, their claim to durability under service conditions has not yet been fully established. It may be stated, however, that tests made on iron by the Office of Public Roads have uniformly indicated that segregated impurities present in iron affect its power to resist corrosion in a marked degree. The tests of the Office of Public Roads, in fact, formed the basis for the development of the pure-iron industry.

Corrugated-iron culvert pipe should be laid in the same manner as vitrified clay and cast-iron pipe. Table 5 gives dimensions, weights,

and prices as furnished by a leading manufacturer of pure iron-corrugated culvert pipe and is representative. The prices are f. o. b. factory and are subject to variations.

TABLE 5.—*Pure iron corrugated culvert pipe.*[1]

Diameter.	Gauge No.	Weight per linear foot.	Price per linear foot, net.
Inches.		*Pounds.*	
10	16	9	$0.80
12	16	11	.90
15	16	13	1.00
18	16	16	1.25
20	16	20	1.40
24	14	25	1.75
30	14	30	2.50
36	14	38	3.40
42	14	45	4.50
48	14	52	5.25

[1] F. o. b. factory.

STONE BOX CULVERTS.

Stone as a material of which to construct box culverts has been largely superseded by reinforced concrete. Where stone of a suitable character abounds, however, it frequently presents advantages in point of economy, and, when properly selected and laid, gives very satisfactory results.

The floor of a stone box culvert, unless the natural material is very firm, should be paved with flat stones not less than 12 inches deep, set on edge at right angles to the line of the culvert and grouted with cement mortar. Where the foundation is of such material as well compacted gravel, it is usually sufficient to build a cross wall or baffle wall at each end.

The side and end walls should be constructed of sound durable stone, not less than 6 inches thick and laid in cement mortar. At least one-half of the stone in each course should consist of headers reaching entirely through the wall. The walls should in every case extend down to a good foundation and below the frost line, and where the foundation lacks firmness, a monolithic concrete footing about 8 inches thick should be used.

Plate III shows the customary method of constructing these culverts, and Table 6 gives dimensions of walls and covers for all sizes in ordinary use.

TABLE 6.—*Dimensions and approximate contents of stone box culverts of type shown in Plate III.*

Items.	Size of opening (span × depth).						
	2 by 2 feet.	2 by 3 feet.	3 by 3 feet.	3 by 4 feet.	4 by 4 feet.	4 by 5 feet.	5 by 5 feet.
Dimensions:							
Cover stones—	*Ft. in.*	*Ft. in.*	*Ft. in.*	*Ft. in.*	*Ft. in.*	*Ft. in.*	*Ft. in.*
Thickness	10	10	12	12	12	12	15
Length	4 0	4 0	5 0	5 0	6 0	6 0	7 0
Side walls—							
Top thickness	1 6	1 6	1 6	1 6	2 0	2 0	2 0
Bottom thickness	2 0	2 0	2 6	2 6	3 0	3 6	3 6
Height	3 6	4 6	5 0	6 0	6 0	7 6	7 6
End walls—							
Length	10 0	13 0	15 6	18 0	18 0	23 0	24 0
Height	5 6	6 6	7 0	8 0	8 0	9 6	10 0
Top thickness	1 6	1 6	1 6	1 6	2 0	2 0	2 0
Bottom thickness	2 0	2 6	2 6	3 0	3 0	3 6	4 0
Approximate contents:	*Cu. yds.*	*Cu. yds.*	*Cu. yds.*	*Cu. yds.*	*Cu. yds.*	*Cu. yds.*	*Cu. yds.*
Two end walls, complete	6.62	11.63	14.94	22.00	23.70	40.52	47.78
Two side walls, per linear foot	.48	.61	.81	.96	1.19	1.67	1.67
Cover, per linear foot	.12	.12	.19	.19	.22	.22	.32
Paving, per linear foot	.09	.09	.14	.14	.19	.19	.23

REINFORCED CONCRETE.

CONCRETE.

GENERAL REQUIREMENTS.

A combination of steel and concrete, made in such a manner that each material will be required to withstand that character of stress for which it is best adapted—that is, tension for steel and compression for concrete—constitutes a form of construction both economical and durable. The advantages of the two materials are combined and their disadvantages in a large degree eliminated.

This form of construction, on account of its economy and simplicity, is especially well suited to highway culverts and short span bridges, when for any reason it is desirable that their superstructures be kept flat. In the case of arch culverts and bridges built of concrete the economy of introducing steel is not always evident and should be demonstrated in any particular case before it is decided that the arch must be reinforced.

The conditions to be met in the construction of reinforced concrete culverts make it desirable, from a standpoint of economy, that a relatively high grade of concrete be used. Any decrease in the strength of the concrete necessitates a corresponding increase in some dimension of the members, and thereby adds to the dead load which the structure must sustain. The data contained in this bulletin are based on the following proportions: A 1 : 2 : 4 mixture (by volume) is specified for the reinforced superstructure, a 1 : $2\frac{1}{2}$: 5 mixture for the walls, and a 1 : 3 : 6 mixture for the footings.

QUANTITIES OF MATERIALS.

The quantities of materials required to make 1 cubic yard of concrete vary with the proportions used and also with the character of the stone and sand. The variations due to the latter are comparatively slight, however, and may usually be neglected in making up preliminary estimates for small structures. Table 7 is based on an average quality of stone and sand.

TABLE 7.—*Quantities of materials for 1 cubic yard of rammed concrete (based on a barrel of 3.8 cubic feet).*[1]

Proportions by parts.			Proportions by volume.			Quantity per cubic yard.		
Cement.	Sand.	Stone.	Packed cement.	Loose sand.	Loose stone.	Cement.	Sand.	Stone.
			Barrels.	*Cu. ft.*	*Cu. ft.*	*Barrels.*	*Cu. yd.*	*Cu. yd.*
1	2	4	1	7.6	15.2	1.57	0.44	0.88
1	$2\frac{1}{2}$	5	1	9.5	19.0	1.30	.46	.92
1	3	6	1	11.4	22.8	1.11	.47	.94

[1] Taylor and Thompson's "Concrete, Plain and Reinforced," New York, 1907.

CEMENT.

The cement used should be a high-grade Portland cement and should comply with the standard specifications of the American Society of Civil Engineers or those of the United States Bureau of Standards. Damaged bags or barrels should always be rejected.

SAND.

A coarse, sharp quartz sand, free from clay or other foreign material, should be used. In places where it is impractical to obtain any other than fine sand the amount of cement should be increased.

BROKEN STONE AND GRAVEL.

Any hard, tough stone or gravel may be used. It should be screened to remove dust or sand and also to remove particles larger than the maximum size desired. For reinforced parts no stone should have a dimension greater than 1 inch. For walls and footings the maximum dimension for stone or gravel will depend on the size of the structure. Usually about 2 inches is a fair maximum size.

MIXING.

Concrete may be mixed either by hand or by machinery. Machine mixing is to be preferred, but the amount of work to be done at any one place in the construction of highway culverts will not usually justify the expense of purchasing a mechanical mixer.

In mixing by hand, observance of the following rules will be found helpful:

(1) A water-tight platform not less than 10 by 12 feet should be provided.

(2) No single batch of concrete should exceed 1 cubic yard.

(3) The size of the batch to be mixed should be based on some integral number of sacks of cement.

(4) Sand in the proper amount should first be spread over the central part of the platform; then the cement should be evenly distributed over the sand and the two thoroughly mixed together while dry. Sufficient water should then be added to make a thin mortar, which should be spread out in a uniform layer. The stone or gravel is spread over this and the whole mass turned with shovels not less than four times until each stone is thoroughly coated with the mortar.

(5) No more than six laborers should be employed in mixing on the same platform. One or two laborers will usually be required to wheel the cement, sand, and stone into place and one to look after the water.

Taylor and Thompson[1] give the following "Data on handling concrete":

Average load of broken stone or gravel for wood wheelbarrow	cubic feet	2.4
Average load of sand for wood wheelbarrow	do	2.5
Large load of broken stone or gravel for iron wheelbarrow on short haul in concrete work	cubic feet	3.0
Large load of sand for iron wheelbarrow on short haul in concrete work	do	3.5
Average load of ordinary concrete[2] for iron wheelbarrow	do	1.9
Large load of ordinary concrete[2] for iron wheelbarrow	do	2.2
Number of shovelfuls of concrete for barrow in average load		13
Number of shovelfuls per barrow in large load		15
Average net time of one man filling wheelbarrow with concrete	minutes	$1\frac{1}{3}$
Quick net time of one man filling wheelbarrow with concrete	do	1
Average quantity of concrete[2] mixed, wheeled 50 feet and rammed, per man per day of 10 hours[3]	cubic yards	2.2
Large quantity of concrete[2] mixed, wheeled 50 feet and rammed, per man per day of 10 hours[3]	cubic yards	3.0
Average quantity of concrete[2] laid as above with a gang of 15 men per day of 10 hours[3]	cubic yards	33
Large quantity of concrete[2] laid as above with a gang of 15 men per day of 10 hours[3]	cubic yards	47
Approximate average quantity of concrete[2] leveled and rammed in 6-inch layers per man per day of 10 hours	cubic yards	11
Approximate large quantity of concrete[2] leveled and rammed in 6-inch layers per man per day of 10 hours	cubic yards	16
Approximate average surface of rough-braced plank form built and removed by one carpenter per day of 10 hours	square yards	25

WATER.

Water used in mixing should be clean, reasonably clear and free from strong alkalis, acids, or other injurious materials.

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[1] Op. cit.

[2] All measurements of concrete are reduced to terms of quantity in place after ramming.

[3] Note that the leveling and ramming, but not the labor on forms, are included in this item.

When concrete is to be mixed in freezing weather—which is to be avoided when possible—it will be found helpful to add about 1 pound of salt to 12 gallons of water for each degree Fahrenheit below the freezing point of water.

DEPOSITING.

Concrete should be deposited in place immediately after mixing. It should be deposited in layers not over 6 inches in thickness, and tamped until water flushes to the surface. No concrete should be deposited in running water, and when deposited in still water a chute should be used.

FORMS.

Forms should be built true to dimensions and be sufficiently well braced to prevent yielding during the process of depositing and tamping the concrete. They should be built of selected lumber of even thickness, free from loose knots or flaws of any nature. The surfaces coming into contact with the concrete should be thoroughly wet immediately before the latter is deposited.

REMOVING FORMS.

The length of time that concrete must set before the forms may be safely removed depends upon the weather conditions, the strain that is to be withstood, and upon the manner of mixing the materials. It is usually safe to remove forms from massive abutments and walls in from 24 to 72 hours. Forms for reinforced superstructures and all supporting forms should ordinarily be left undisturbed at least 10 days, and in cold or wet weather the time should be doubled. It is desirable that the forms be removed as soon as possible after the proper period of time has elapsed; otherwise finishing the surface will be more difficult.

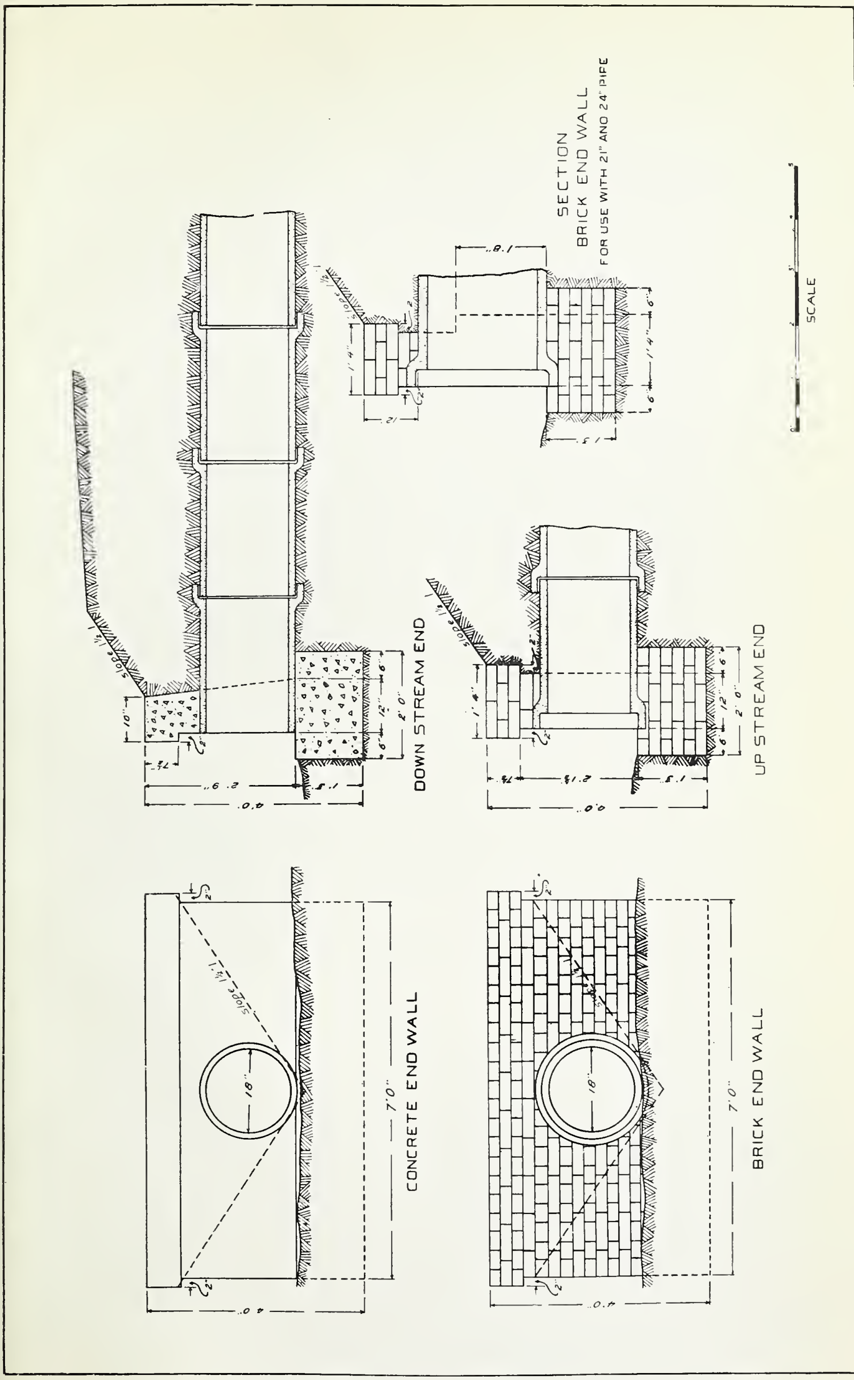
FINISHING.

Any cavities which appear when the forms are removed should be filled with mortar mixed in the same proportion as that used in the concrete. The exposed surfaces of the structure should then be rubbed down with a wooden float and sand grout, and any fins or ridges due to imperfections in the forms should be removed. Plastering should never be permitted.

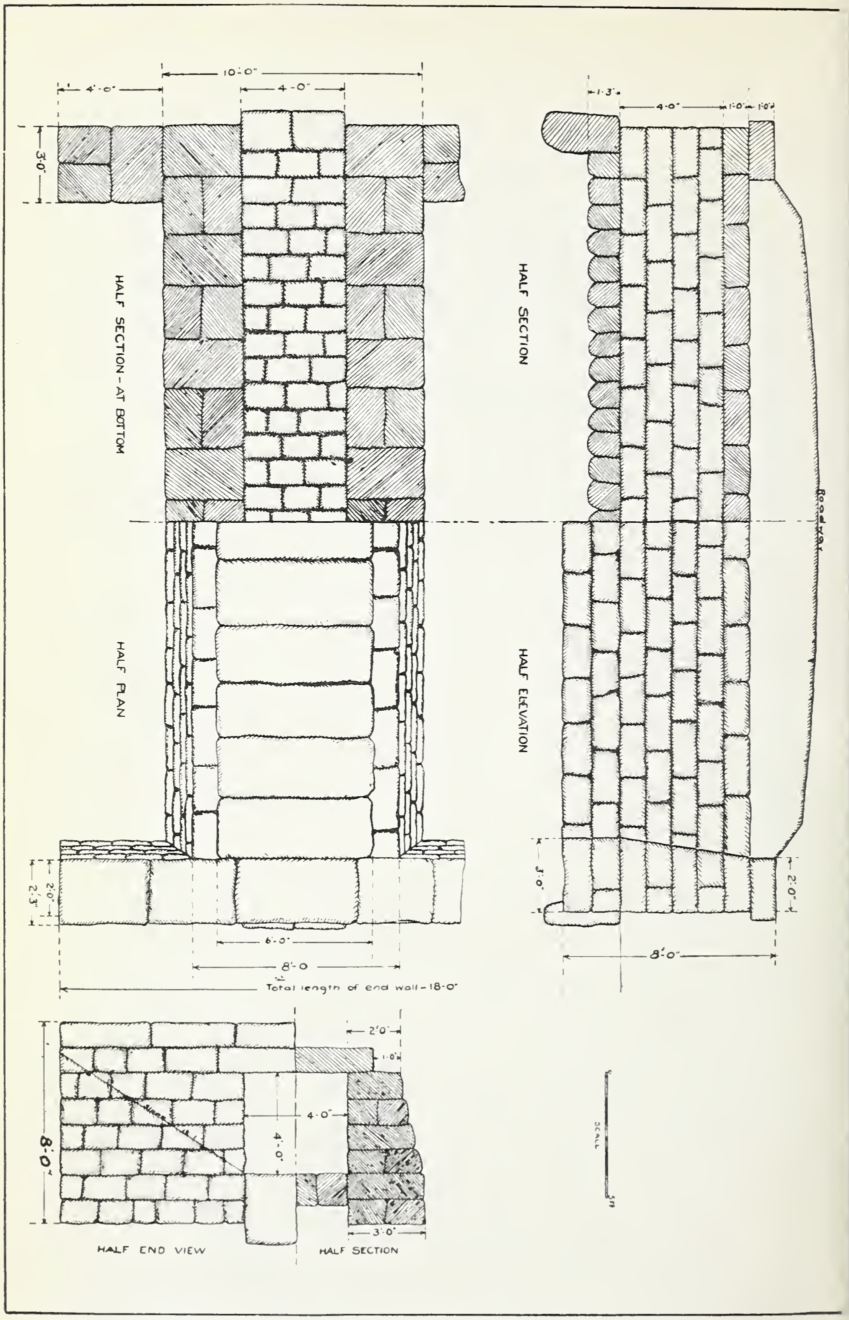
REINFORCEMENT.

GENERAL REQUIREMENTS FOR STEEL.

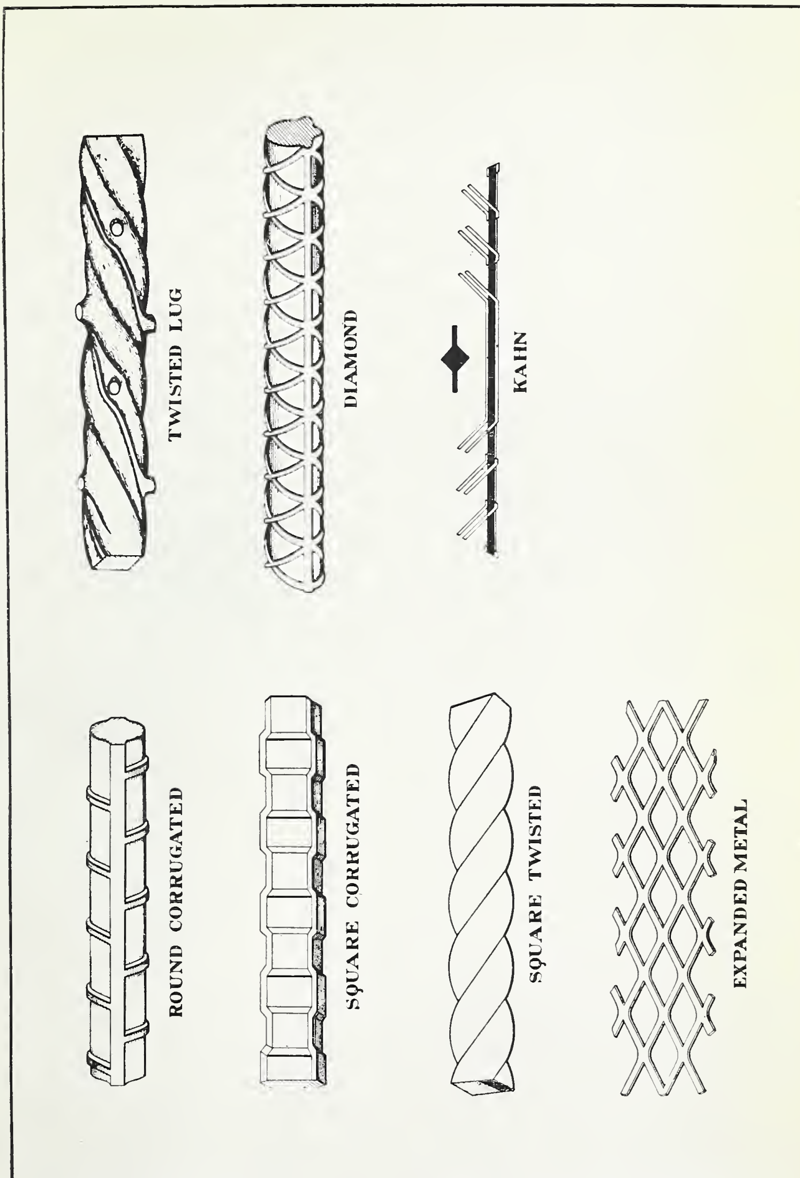
Reinforcing bars should be made from steel having a safe strength of not less than 16,000 pounds per square inch, and should possess sufficient malleability to be readily bent into the desired shapes while cold. When placed in the concrete they should be free from rust, grease, or foreign materials of any kind; otherwise a perfect bond between the bars and the concrete will not be obtained.



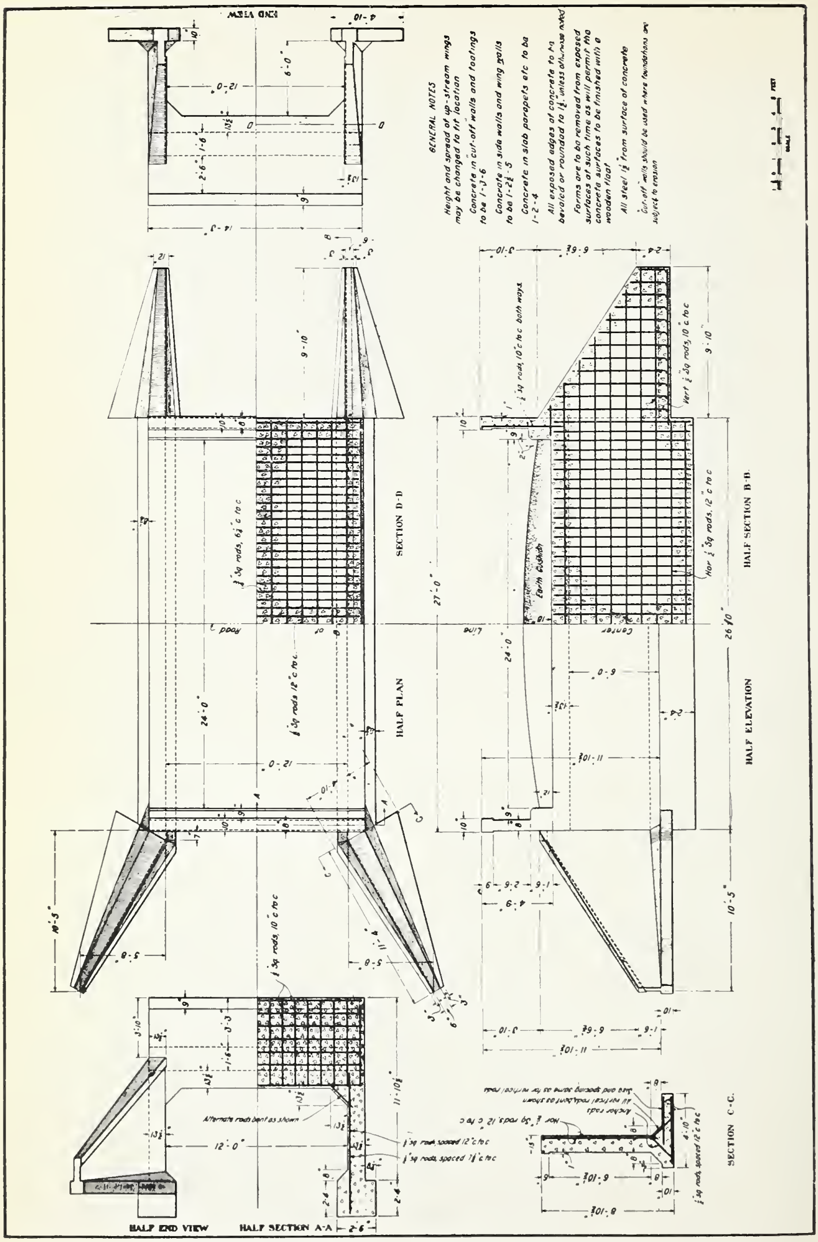
PLAN FOR A VITRIFIED CLAY PIPE CULVERT WITH END WALLS.



PLAN FOR A STONE BOX CULVERT.



TYPES OF DEFORMED BARS.



TYPICAL REINFORCED CONCRETE SLAB BRIDGE, 12 BY 6 FEET OPENING.

FORMS OF BARS.

Many types of patent deformed bars, designed to furnish a "mechanical bond" between concrete and steel, are being manufactured, and can be almost as readily obtained as the plain round or square rods at very little additional cost. (Pl. IV.) They undoubtedly possess advantages over the plain rods, and a larger factor of safety will be obtained by using them. They are not specified, however, for the designs given in this bulletin. Either plain round or plain square rods of the sizes indicated for each may be used. Flat bars, however, should be avoided. Their adhesion to the concrete is much below that of either round or square rods of equivalent area.

Table 8 gives sectional areas and weights per linear foot for all sizes of round and square rods ordinarily used in reinforced concrete construction:

Table 8.—*Sizes and weights of reinforcing bars.*

Diameter or thickness.	Square rods.		Round rods.		Diameter or thickness.	Square rods.		Round rods.	
	Area.	Weight per foot.	Area.	Weight per foot.		Area.	Weight per foot.	Area.	Weight per foot.
Inches.	*Sq. in.*	*Pounds.*	*Sq. in.*	*Pounds.*	*Inches.*	*Sq. in.*	*Pounds.*	*Sq. in.*	*Pounds.*
$\frac{1}{4}$	0.0625	0.212	0.0491	0.167	$1\frac{1}{8}$	1.2656	4.303	0.9940	3.379
$\frac{5}{16}$	.0977	.333	.0767	.261	$1\frac{1}{4}$	1.5625	5.312	1.2272	4.173
$\frac{3}{8}$	.1406	.478	.1104	.375	$1\frac{3}{8}$	1.8906	6.428	1.4849	5.049
$\frac{1}{2}$	.2500	.850	.1963	.667	$1\frac{1}{2}$	2.2500	7.650	1.7671	6.008
$\frac{5}{8}$	.3906	1.328	.3068	1.043	$1\frac{5}{8}$	2.6406	8.978	2.0739	7.051
$\frac{3}{4}$	.5625	1.913	.4418	1.502	$1\frac{3}{4}$	3.0625	10.41	2.4053	8.178
$\frac{7}{8}$	.7656	2.603	.6013	2.044	$1\frac{7}{8}$	3.5756	11.95	2.7612	9.388
1	1.0000	3.400	.7854	2.670	2	4.0000	13.60	3.1416	10.68

SLAB-TOP CULVERTS AND BRIDGES.

GENERAL COMPUTATIONS.

Reinforced concrete culverts and bridges of the slab-top type have been successfully used for a number of years. They are well adapted for short spans and are very easily constructed. The upper limiting span for economy appears to be from 12 to 16 feet, depending on local conditions.

Plate V shows a typical design for a 12-foot span, and Table 9 contains all the data necessary for designing slab tops for culverts and bridges, varying in span from 2 to 16 feet. The computations were based on the following assumptions:

Concrete:
  Proportions.. 1 : 2 : 4
  Safe compressive strength—
    Dead load per square inch..................pounds.. 700
    Live load [1] per square inch...................do.... 470
  Modulus of elasticity.. 2,500,000

[1] In making computations the live load was increased by 50 per cent for impact and the dead load value was used.

Steel:

Medium.

Safe tensile strength—

Dead load per square inch	pounds	16,000
Live load [1] per square inch	do	10,700
Modulus of elasticity		30,000,000

Cushion—

The minimum allowable cushion between the top of the slab and the surface of the roadway is 12 inches. It should consist of material all of which will pass through a 2-inch ring.

Loading—

The dead load, uniformly distributed, is assumed to be 150 pounds per square foot plus the weight of the slab.

The live load is assumed to be 2,000 pounds concentrated at the center on a strip 1 foot wide. Taking into account the effect of the cushion and the slab in distributing concentrated loads, this assumption is sufficiently "severe" to provide for all ordinary highway traffic up to and including a 15-ton road roller.

Formulæ (based on foregoing assumptions)—

$$\frac{\text{Area of steel}}{\text{Area of concrete above steel}}=0.0075$$

The resisting moment in inch-pounds of strip 1 foot wide equals M_R, and the depth of the slab to the steel, in inches, equals d. Then $M_R=1272d^2$.

If it is desired to assume a loading different from that for which the table has been computed, the required depth of slab and the amount of steel may be readily obtained by substituting the proper values in the above formulæ.

[1] In making computations the live load was increased by 50 per cent for impact and the dead load value was used.

TABLE 9.—*Data for designing slab superstructure.*

Span.	Depth of slab to C. G. of steel.	Total depth of slab.	Area of steel per foot of width.	Suggestions as to size and spacing of reinforcing bars.	Longitudinal reinforcement against temperature changes.	Weight of slab per square foot.	Volume[1] of concrete in strip of slab 1 foot wide.		Weight of steel in strip of slab 1 foot wide.		Thickness of of reinforced abutment walls.	Top thickness of plain abutment walls.
							Reinforced abutments.	Plain abutments.	Square.	Round.		
Feet.	*Inches.*	*Inches.*	*Sq. in.*			*Pounds.*	*Cu. yds.*	*Cu. yds.*	*Pounds.*	*Pounds.*	*Inches.*	*Inches.*
2	4½	6	0.360	½ inch square, 8 inches c. to c., or ½ inch round, 6 inches c. to c.	½-inch square rods, 12 inches center to center, or ½-inch round rods, 10 inches center to center, for all spans.	75	0.083	0.110	6.38	6.40	6	9
3	5½	7	.450	½ inch square, 6 inches c. to c., or ½ inch round, 5 inches c. to c.		88	.128	.142	10.20	9.60	7	9
4	6	7½	.573	½ inch square, 5½ inches c. to c., or ⅝ inch round, 7 inches c. to c.		94	.165	.184	13.52	12.94	7½	10
5	6½	8	.585	½ inch square, 5 inches c. to c., or ⅝ inch round, 6 inches c. to c.		100	.206	.222	18.36	18.36	8	10
6	7½	9	.653	⅝ inch square, 7 inches c. to c., or ¾ inch round, 8 inches c. to c.		113	.271	.299	22.93	22.50	9	12
7	8	9½	.720	⅝ inch square, 6½ inches c. to c., or ¾ inch round, 7 inches c. to c.		119	.321	.346	27.64	28.29	9½	12
8	9	10½	.810	⅝ inch square, 5¾ inches c. to c., or ¾ inch round, 6½ inches c. to c.		132	.401	.428	35.36	34.93	10½	13
9	10	11½	.900	⅝ inch square, 5¼ inches c. to c., or ¾ inch round, 5¾ inches c. to c.		144	.490	.518	41.89	42.48	11½	14
10	10½	12	.945	⅝ inch square, 5 inches c. to c., or ¾ inch round, 5½ inches c. to c.		150	.556	.580	47.60	48.13	12	14
11	11	12½	.990	¾ inch square, 6¾ inches c. to c., or ⅞ inch round, 7¼ inches c. to c.		157	.625	.658	54.41	53.58	12½	15
12	11½	13½	1.062	¾ inch square, 6½ inches c. to c., or ⅞ inch round, 6¾ inches c. to c.		169	.734	.769	62.47	61.27	13½	16
13	12½	14½	1.134	¾ inch square, 6 inches c. to c., or ⅞ inch round, 6¼ inches c. to c.		181	.852	.889	69.29	70.07	14½	17
14	13½	15½	1.206	¾ inch square, 5½ inches c. to c., or ⅞ inch round, 6 inches c. to c.		194	.980	1.002	79.53	77.41	15½	17
15	14	16	1.269	¾ inch square, 5¼ inches c. to c., or ⅞ inch round, 5¾ inches c. to c.		200	1.070	1.103	87.93	85.32	16	18
16	15	17	1.350	¾ inch square, 5 inches c. to c., or ⅞ inch round, 5¼ inches c. to c.		212	1.211	1.228	97.09	97.70	17	18

[1] Volume given includes chamfered corners and that part of abutment walls above dotted line AB, figure 3 and Plate XII.

BOX CULVERTS.

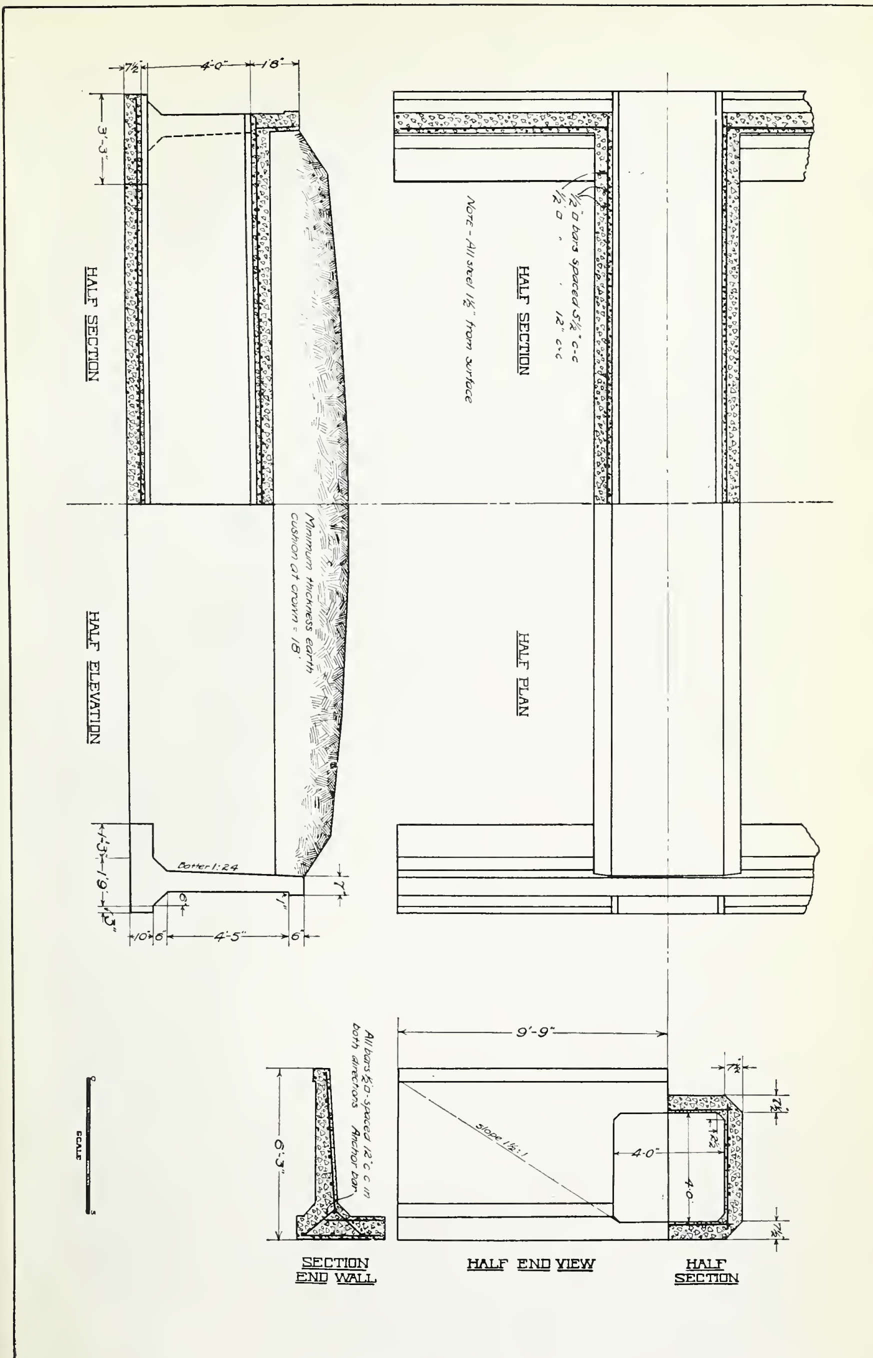
The reinforced-concrete box culvert is a special application of the slab superstructure, and the cover slab may be designed directly by reference to the table of data for use in designing slab superstructures. The most severe condition of loading which could reasonably be assumed for the bottom slab is that it would be loaded in the same way as the cover slab. It may, therefore, be safely given the same dimensions and reinforced in the same manner as the cover slab.

The side walls, provided their height is no greater than the length of the span, could never be subjected to a condition of loading as severe as that assumed for the top and bottom slabs. It is convenient, however, to reinforce the side walls by bending the reinforcing bars for the top and bottom into the form of U's, making the legs of the U's sufficiently long for those from the top to interlap about 1 foot with those from the bottom. The thickness of the side walls may also be made the same as that of the top and bottom slabs. Table 10 gives additional data on box culverts designed as indicated above, and Plate VI shows a typical design.

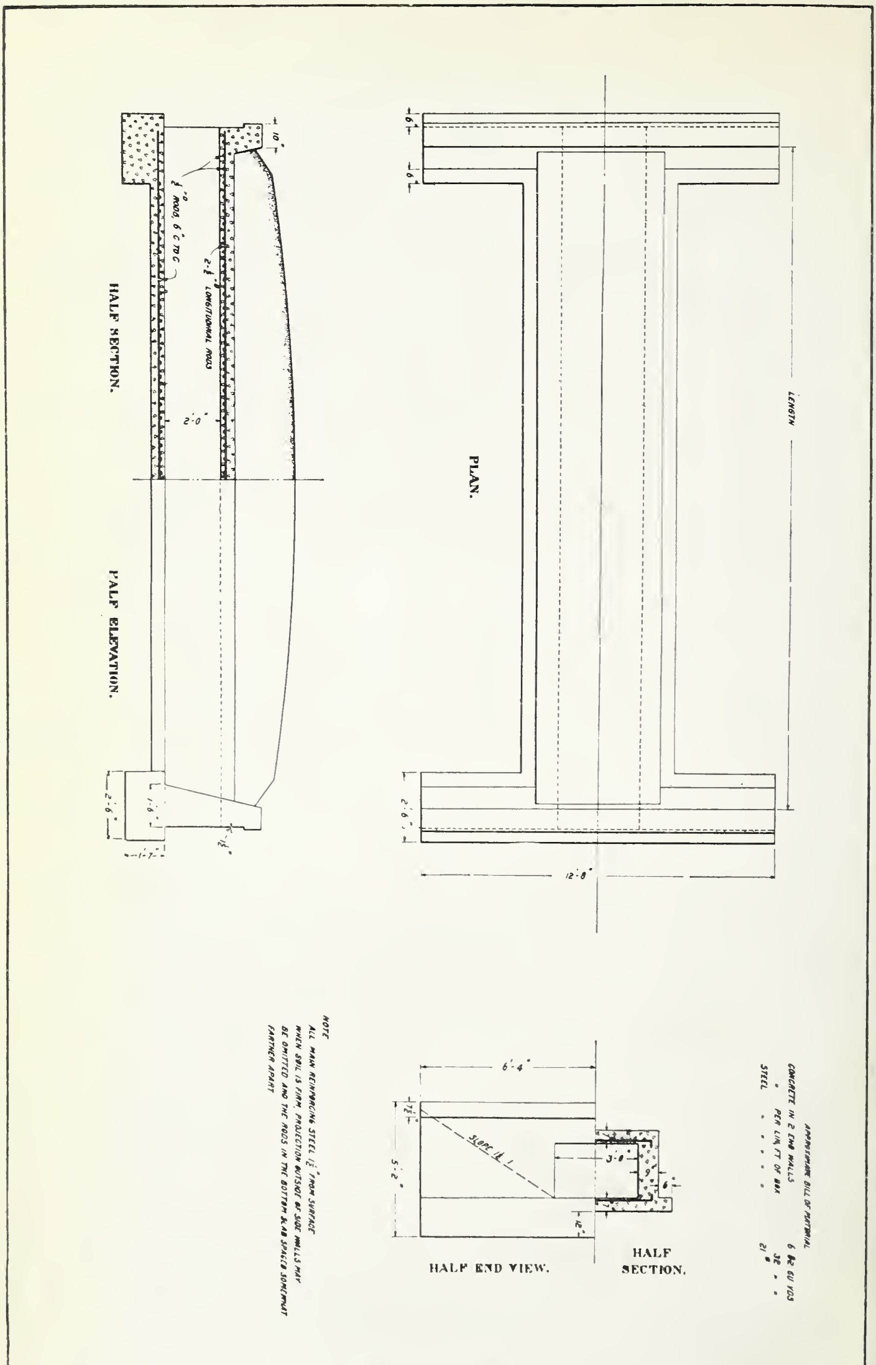
TABLE 10.—*Data on reinforced-concrete box culverts.*

Size of opening (height×span).	1 foot 6 inches by 1 foot 6 inches.	2 by 2 feet.	2 by 3 feet.	2 by 4 feet.	3 by 3 feet.	3 by 4 feet.	3 by 5 feet.	4 by 4 feet.	4 by 5 feet.	5 by 5 feet.
Area of waterway.square feet..	2.25	4.0	6.0	8.0	9.0	12.0	15.0	16.0	20.0	25.0
End walls:										
Height (over all), feet and inches....................	3 6	4 0	4 2	4 3	5 2	5 3	5 4	6 3	8 4	7 4
Length...feet and inches..	9 6	11 6	12 8	13 8	15 8	16 8	17 10	19 6	20 10	23 10
Top thickness......inches..	7	7	7	7	7	7	7	7	7	8
Depth of footing....do....	10	10	10	10	10	10	10	10	10	10
Width of footing, feet and inches......................	1 8	1 11	2 0	2 1	2 8	2 8	2 9	3 3	3 4	3 11
Concrete.....cubic yards..	1.80	2.62	2.90	3.08	4.84	5.09	5.36	7.66	8.14	12.17
Cement...........barrels..	2.34	3.41	3.77	4.00	6.29	6.62	6.97	9.96	10.58	15.81
Sand........cubic yards..	.83	1.21	1.33	1.42	2.23	2.34	2.47	3.52	3.75	5.60
Stone...............do....	1.66	2.41	2.66	2.84	4.46	4.68	4.94	7.04	7.50	11.19
Steel.............pounds..	220	306	344	378	533	570	615	766	820	1,145
Box:										
Thickness of walls.inches..	6	6	7	7½	7	7½	8	7½	8	8
Concrete, cubic yards per linear foot..................	.129	.166	.241	.307	.285	.354	.428	.400	.478	.528
Cement, barrels per linear foot......................	.203	.261	.378	.482	.447	.556	.671	.628	.750	.829
Sand, cubic yards per linear foot..................	.057	.073	.106	.135	.126	.156	.188	.176	.210	.232
Stone, cubic yards per linear foot..................	.114	.146	.212	.270	.252	.312	.376	.352	.420	.464
Steel, pounds per linear foot......................	12.65	13.82	19.75	22.7	21.5	26.3	31.6	29.8	35.5	39.3

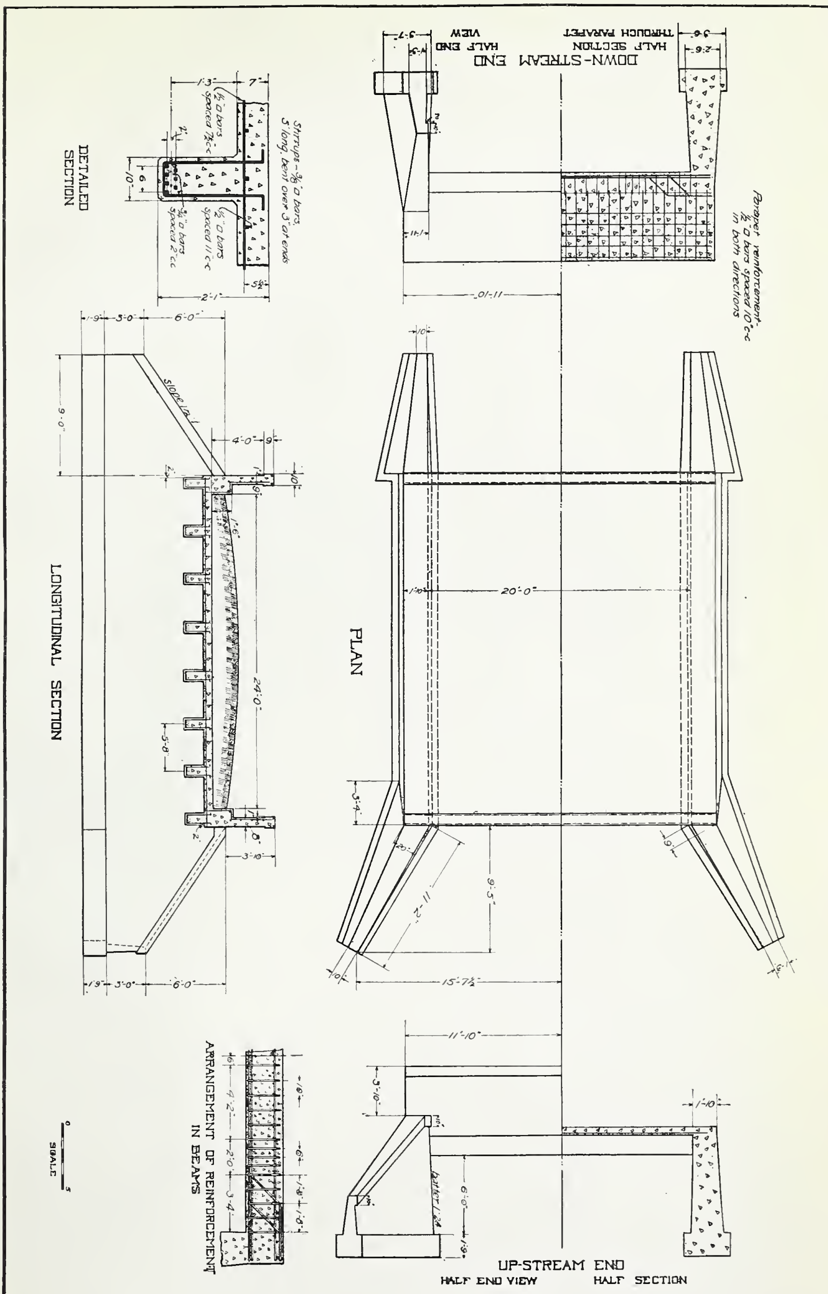
Local conditions will frequently require modifications in this design. For example, where the bed of the stream is likely to erode or where deep freezing is likely to occur, an apron should extend below the end wall. Moreover, where the foundation material is unstable the bottom slab should project outside of the side walls in order to distribute the load better. Again, where cement, sand, and



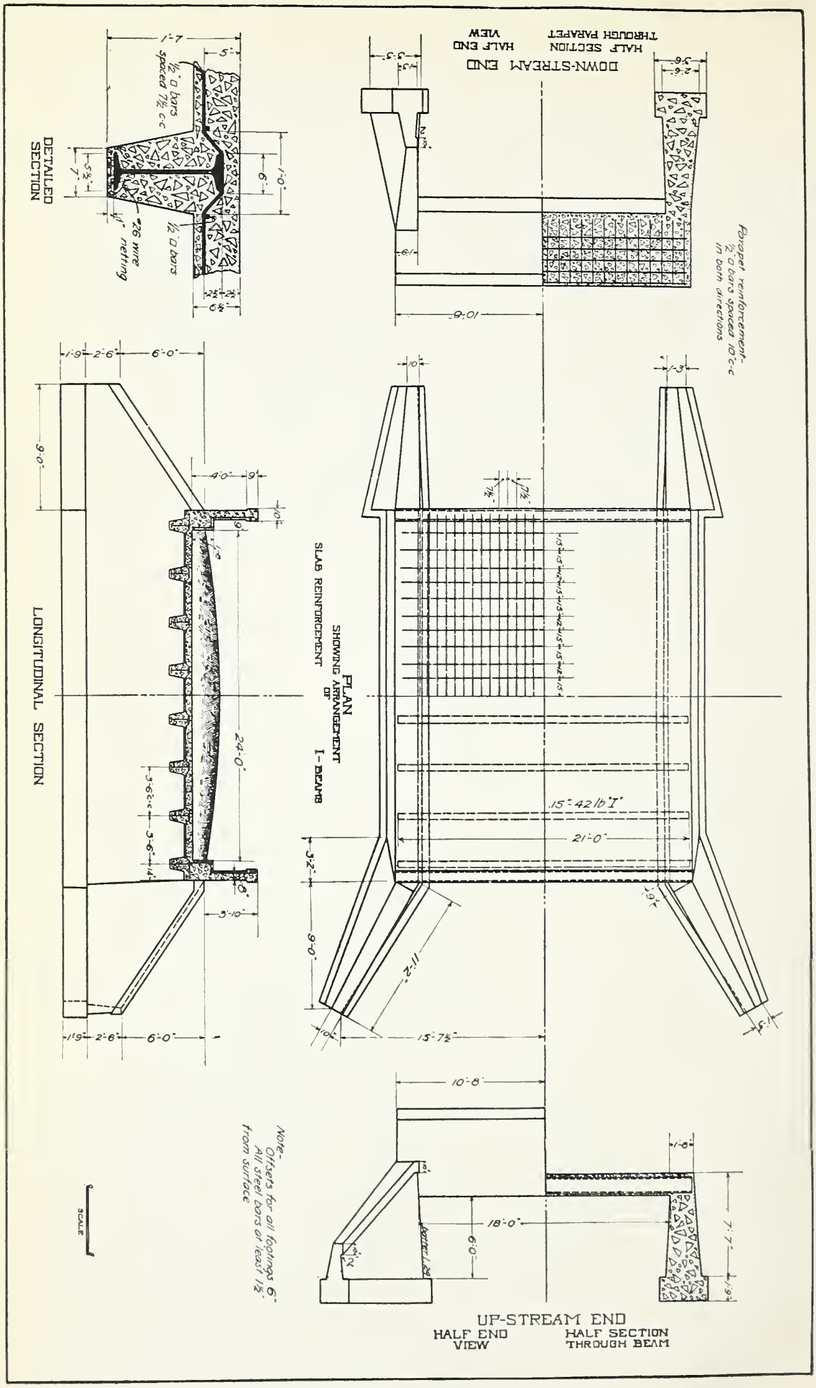
PLAN FOR A REINFORCED CONCRETE BOX CULVERT.



TYPICAL REINFORCED CONCRETE BOX CULVERT, 3 BY 2 FEET OPENING.



TYPICAL DESIGN FOR A T-BEAM BRIDGE.



TYPICAL DESIGN FOR AN I-BEAM BRIDGE.

broken stone or gravel may be readily and cheaply obtained, it is frequently well to construct the side and end walls of plain concrete. Plate VII shows a design for a box culvert which takes into account some of these conditions.

T-BEAM SUPERSTRUCTURES.

This type of construction has been employed for spans up to about 50 feet in length. For spans greater than 30 feet, however, it is of doubtful economy. The lower economical limit will in practically all cases lie between 10 and 16 feet.

Tables 11 and 12 contain all data necessary for designing T-beam superstructures for spans varying in length from 10 to 30 feet. Since variation in the width of the roadway and in the relative cost of form construction influence the economical spacing of beams, several different spacings have been considered. The smaller spacings are usually economical of concrete and steel, but the cost of forms must also be considered. The beams should preferably be so spaced that an even number will be required. For spacings intermediate between those shown, the beam dimensions and area of reinforcing steel may be obtained from the tables with sufficient accuracy by means of interpolation.

TABLE 11.—*Dimensions, beams for reinforced-concrete T-beam culverts.*

Span.	Spacing of beams (center to center).	Web dimensions.		Total depth of T-beam.	Depth from top of slab to C. G. of steel in beam.	Area of horizontal reinforcement in beam.	Weight of beam per linear foot used in design.	Volume of one beam between abutments.	Weight of steel in one beam (including stirrups).		Horizontal reinforcement.		Number of horizontal rods bent up and distance from center (for round and square rods).	Spacing of $\frac{3}{8}$-inch vertical stirrups (beginning at ends of beams.)	
		Width.	Depth.						Round.	Square.	Round rods.	Square rods.		Round rods.	Square rods.
Ft.	*Ft.*	*In.*	*In.*	*In.*	*In.*	*Sq.in.*	*Lbs.*	*Cu.ft.*	*Lbs.*	*Lbs.*					
	3	$6\frac{1}{2}$	12	18	16	1.56	81	0.201	75	78	2 1-inch........	2 $\frac{7}{8}$-inch........	....	3 at 6 inches, rest 7 inches.	7 inches throughout.
10	4	8	13	$20\frac{1}{2}$	$18\frac{1}{2}$	1.84	108	.267	85	91	2 1-inch, and 1 $\frac{5}{8}$-inch.	2 $\frac{3}{4}$-inch and 1 $\frac{7}{8}$-inch.	....	3 at 6 inches, rest 9 inches.	3 at 6 inches, rest 9 inches.
	5	8	16	25	23	1.90	133	.329	99	92	2 $\frac{7}{8}$-inch, and 1 1-inch.	2 $\frac{7}{8}$-inch and 1 $\frac{5}{8}$-inch.	....	5 at 5 inches, rest 8 inches.	3 at 7 inches, rest 11 inches.
	3	7	13	19	17	1.82	95	.281	102	107	2 1-inch and 1 $\frac{5}{8}$-inch.	2 $\frac{7}{8}$-inch and 1 $\frac{5}{8}$-inch.	....	3 at 6 inches, rest 8 inches.	8 inches throughout. m
12	4	$8\frac{1}{2}$	15	$22\frac{1}{2}$	$20\frac{1}{2}$	2.11	132	.394	119	120	2 1-inch and 1 $\frac{7}{8}$-inch.	2 $\frac{7}{8}$-inch and 1 $\frac{3}{4}$-inch.	....	5 at 5 inches, 3 at 6 inches, rest 10 inches.	4 at 6 inches, rest 10 inches.
	5	9	17	26	24	2.34	159	.472	135	146	3 1-inch........	2 $\frac{7}{8}$-inch and 1 1-inch.	....	4 at 4 inches, 4 at 6 inches, rest 10 inches.	5 at 5 inches, rest 11 inches.
	3	8	$13\frac{1}{2}$	$19\frac{1}{2}$	$17\frac{1}{2}$	2.21	113	.389	140	149	2 $1\frac{1}{8}$-inch and 1 $\frac{5}{8}$-inch.	3 $\frac{7}{8}$-inch........	....	3 at 5 inches, rest 8 inches.	3 at 5 inches, rest 8 inches.
14	4	$8\frac{1}{2}$	16	$23\frac{1}{2}$	21	2.56	142	.490	157	177	2 1-inch and 1 $1\frac{1}{8}$-inch.	2 1-inch and 1 $\frac{7}{8}$-inch.	....	4 at 5 inches, 3 at 6 inches, rest 10 inches.	7 at 6 inches, rest 10 inches.
	5	$9\frac{1}{2}$	18	27	25	2.80	177	.616	178	190	2 1-inch and 1 $1\frac{1}{4}$-inch.	3 1-inch........	....	4 at 4 inches, 5 at 6 inches, rest 12 inches.	4 at 6 inches, 3 at 8 inches, rest 12 inches.
	3	8	15	21	19	2.51	125	.494	176	180	2 1-inch and 1 $1\frac{1}{8}$-inch.	2 $\frac{7}{8}$-inch and 1 1-inch.	....	6 at 6 inches, rest 9 inches.	3 at 6 inches, rest 9 inches.
16	4	9	17	$24\frac{1}{2}$	$22\frac{1}{2}$	2.96	159	.630	208	215	3 $1\frac{1}{8}$-inch........	3 1-inch........	....	5 at 4 inches, 4 at 7 inches, rest 11 inches.	4 at 5 inches, 3 at 7 inches, rest 11 inches.
	5	10	20	29	26	3.36	208	.823	222	234	5 $\frac{7}{8}$-inch and 2 $\frac{1}{2}$-inch.	4 $\frac{3}{4}$-inch and 3 $\frac{5}{8}$-inch.	2 at 5 feet and 2 at 6 feet 6 inches.	3 at 12 inches, 3 at 6 inches, rest 12 inches.	3 at 12 inches, 3 at 6 inches, rest 12 inches
	3	$8\frac{1}{2}$	16	22	19	3.09	142	.630	224	235	7 $\frac{3}{4}$-inch........	8 $\frac{5}{8}$-inch........	2 at 6 feet and 2 at 7 feet 6 inches.	9 inches throughout...	9 inches throughout.
18	4	$9\frac{1}{2}$	$18\frac{1}{2}$	26	23	3.54	183	.814	264	270	4 $\frac{3}{4}$-inch and 3 $\frac{7}{8}$-inch.	5 $\frac{3}{4}$-inch and 2 $\frac{5}{8}$-inch.	2 at 6 feet and 2 at 7 feet 6 inches.	3 at 11 inches, 6 at 6 inches, rest 11 inches.	3 at 11 inches, 3 at 7 inches, rest 11 inches.
	5	$10\frac{1}{2}$	21	30	27	3.95	230	1.020	296	293	6 $\frac{7}{8}$-inch and 2 $\frac{1}{2}$-inch.	7 $\frac{3}{4}$-inch........	2 at 6 feet and 2 at 7 feet 6 inches.	2 at 12 inches, 6 at 6 inches, rest 9 inches.	3 at 12 inches, 3 at 6 inches, rest 13 inches.

	3	9	16	22	19	3.70	150	.741	302	309	5 $\frac{3}{4}$-inch and 2 1-inch.	6 $\frac{3}{4}$-inch and 1 $\frac{5}{8}$-inch.	2 at 7 feet and 2 at 8 feet 6 inches.	4 at 9 inches, 4 at 6 inches, rest 9 inches.	9 inches throughout.
20	4	10	19	26½	23½	4.14	198	.977	337	341	7 $\frac{7}{8}$-inch........	6 $\frac{3}{4}$-inch and 1 $\frac{7}{8}$-inch.	2 at 7 feet and 2 at 8 feet 6 inches.	3 at 11 inches, 6 at 6 inches, rest 11 inches.	3 at 11 inches, 6 at 7 inches, rest 11 inches.
	5	11	22	31	28	4.55	252	1.245	368	375	5 $\frac{7}{8}$-inch and 2 1-inch.	4 $\frac{3}{4}$-inch and 3 $\frac{7}{8}$-inch.	2 at 7 feet and 2 at 8 feet 6 inches.	3 at 12 inches, 4 at 5 inches, 3 at 9 inches, rest 13 inches.	3 at 12 inches, 3 at 7 inches, 4 at 8 inches, rest 13 inches.
	3	9	17½	23½	20½	3.99	163	.891	357	364	4 $\frac{3}{4}$-inch and 3 1-inch.	6 $\frac{3}{4}$-inch and 1 $\frac{7}{8}$-inch.	2 at 8 feet and 2 at 9 feet 6 inches.	4 at 10 inches, 4 at 6 inches, rest 10 inches.	10 inches throughout.
22	4	11	19	26½	23½	4.92	217	1.183	427	440	4 1-inch and 3 $\frac{7}{8}$-inch.	5 $\frac{7}{8}$-inch and 2 $\frac{3}{4}$-inch.	2 at 8 feet and 2 at 9 feet 6 inches.	3 at 11 inches, 4 at 4 inches, 3 at 7 inches, rest 11 inches.	3 at 11 inches, 3 at 5 inches, 3 at 7 inches, rest 11 inches.
	5	12	21½	30½	27½	5.48	268	1.459	484	492	7 1-inch........	6 $\frac{7}{8}$-inch and 1 1-inch.	2 at 8 feet and 2 at 9 feet 6 inches.	3 at 12 inches, 4 at 5 inches, 5 at 6 inches, rest 9 inches.	3 at 12 inches, 4 at 6 inches, 3 at 9 inches, rest 12 inches.
	4	11½	19	26½	23½	5.70	228	1.349	527	535	9 $\frac{7}{8}$-inch and 1 $\frac{5}{8}$-inch.	7 $\frac{5}{8}$-inch and 3 1-inch.	2 at 7 feet 6 inches, 2 at 9 feet, and 2 at 10 feet 6 inches.	5 at 11 inches, 3 at 5 inches, 4 at 7 inches, rest 11 inches.	5 at 11 inches, 3 at 7 inches, rest 11 inches.
24	5	13	22	31	28	6.24	297	1.766	583	576	5 1-inch and 4 $\frac{7}{8}$-inch.	7 $\frac{3}{4}$-inch and 3 $\frac{7}{8}$-inch.	2 at 7 feet 6 inches, 2 at 9 feet, and 2 at 10 feet 6 inches.	4 at 13 inches, 5 at 6 inches, 3 at 9 inches, rest 13 inches.	4 at 13 inches, 4 at 9 inches, rest 13 inches.
	6	13	23½	34½	31½	6.55	318	1.886	613	609	6 $\frac{7}{8}$-inch and 3 $1\frac{1}{8}$-inch.	5 1-inch and 4 $\frac{5}{8}$-inch.	2 at 7 feet 6 inches, 2 at 9 feet, and 2 at 10 feet 6 inches.	5 at 10 inches, 5 at 7 inches, 4 at 10 inches, rest 15 inches.	4 at 14 inches, 2 at 6 inches, 3 at 10 inches, rest 15 inches.
	4	11½	20½	28	25	6.12	246	1.576	604	614	5 $\frac{7}{8}$-inch and 4 1-inch.	7 $\frac{7}{8}$-inch and 2 $\frac{5}{8}$-inch.	2 at 8 feet 6 inches, 2 at 10 feet, and 2 at 11 feet 6 inches.	6 at 10 inches, 3 at 8 inches, rest 12 inches.	5 at 12 inches, 3 at 8 inches, rest 12 inches.
26	5	13	22½	31½	28½	7.05	305	1.936	692	704	9 1-inch........	7 $\frac{3}{4}$-inch and 2 $1\frac{1}{4}$-inch.	2 at 8 feet 6 inches, 2 at 10 feet, and 2 at 11 feet 6 inches.	4 at 14 inches, 5 at 7 inches, 4 at 9 inches, rest 14 inches.	4 at 14 inches, 4 at 7 inches, 3 at 9 inches, rest 14 inches.
	6	13½	24	35	32	7.43	337	2.167	752	751	7 1-inch and 2 $1\frac{1}{8}$-inch.	9 $\frac{7}{8}$-inch and 1 $\frac{3}{4}$-inch.	2 at 8 feet 6 inches, 2 at 10 feet, and 2 at 11 feet 6 inches.	4 at 14 inches, 3 at 4 inches, 6 at 6 inches, 3 at 10 inches, rest 15 inches.	4 at 14 inches, 5 at 7 inches, 3 at 10 inches, rest 15 inches.
	4	13	21	28½	25½	6.83	284	1.966	722	734	8 1-inch and 1 $\frac{7}{8}$-inch.	9 $\frac{7}{8}$-inch........	2 at 9 feet 6 inches, 2 at 11 feet, and 2 at 12 feet 6 inches.	5 at 12 inches, 3 at 6 inches, 3 at 8 inches, rest 12 inches.	5 at 12 inches, 3 at 8 inches, rest 12 inches.
28	5	13½	23	32	29	7.88	324	2.236	840	842	5 1-inch and 4 $1\frac{1}{8}$-inch.	9 $\frac{7}{8}$-inch and 1 1-inch.	2 at 9 feet 6 inches, 2 at 11 feet, and 2 at 12 feet 6 inches.	4 at 14 inches, 5 at 5 inches, 5 at 7 inches, 3 at 9 inches, rest 14 inches.	4 at 14 inches, 5 at 7 inches, 3 at 9 inches, rest 14 inches.
	6	13½	25½	36	33	8.20	352	2.479	879	889	8 1-inch and 2 $1\frac{1}{8}$-inch.	6 1-inch and 4 $\frac{3}{4}$-inch.	2 at 9 feet 6 inches, 2 at 11 feet, and 2 at 12 feet 6 inches.	4 at 14 inches, 3 at 4 inches, 6 at 6 inches, 3 at 10 inches, rest 15 inches.	4 at 14 inches, 3 at 5 inches, 4 at 8 inches, 3 at 10 inches, rest 16 inches.

TABLE 11.—*Dimensions, beams for reinforced-concrete* T-*beam culverts*—Continued.

Span.	Spacing of beams (center to center).	Web dimensions.		Total depth of T-beam.	Depth from top of slab to C. G. of steel in beam.	Area of horizontal reinforcement in beam.	Weight of beam per linear foot used in design.	Volume of one beam between abutments.	Weight of steel in one beam (including stirrups).		Horizontal reinforcement.		Number of horizontal rods bent up and distance from center (for round and square rods).	Spacing of $\frac{3}{4}$-inch vertical stirrups (beginning at ends of beams).	
		Width.	Depth.						Round.	Square.	Round rods.	Square rods.		Round rods.	Square rods.
Ft.	*Ft.*	*In.*	*In.*	*In.*	*In.*	*Sq.in*	*Lbs.*	*Cu.ft.*	*Lbs.*	*Lbs.*					
30	4	13	22	$29\frac{1}{2}$	$26\frac{1}{2}$	7.39	297	2.190	846	858	7 1-inch and 2 $1\frac{1}{8}$-inch.	9 $\frac{7}{8}$-inch and 1 $\frac{3}{4}$-inch.	2 at 10 feet 6 inches, 2 at 12 feet, and 2 at 13 feet.	5 at 11 inches, 6 at 5 inches, 3 at 8 inches, rest 13 inches.	4 at 13 inches, 5 at 5 inches, 3 at 8 inches, rest 13 inches.
	5	14	$24\frac{1}{2}$	$33\frac{1}{2}$	$30\frac{1}{2}$	8.42	345	2.554	961	971	7 1-inch and 3 $1\frac{1}{8}$-inch.	8 1-inch and 1 $\frac{3}{4}$-inch.	2 at 10 feet 6 inches, 2 at 12 feet, and 2 at 13 feet.	4 at 14 inches, 3 at 4 inches, 5 at 6 inches, 5 at 7 inches, rest 15 inches.	4 at 14 inches, 5 at 7 inches, 3 at 10 inches, rest 15 inches.
	6	15	26	37	34	9.13	406	3.009	1,040	1,042	8 $1\frac{1}{8}$-inch and 2 $\frac{7}{8}$-inch.	8 1-inch and 2 $\frac{3}{4}$-inch.	2 at 10 feet 6 inches, 2 at 12 feet, and 2 at 13 feet.	4 at 14 inches, 4 at 4 inches, 6 at 6 inches, 3 at 10 inches, rest 15 inches.	4 at 14 inches, 3 at 5 inches, 4 at 8 inches, 3 at 11 inches, rest 16 inches.

TABLE 12.—*Floor slabs for* T-*beam and incased* I-*beam superstructures.*

Spacing of beams[1] (c. to c.).	Depth of slab to C. G. of steel.	Total depth of slab.	Area of steel.	Size and arrangement of reinforcing rods. Square.	Round.	Longitudinal reinforcement. (No. of rods.)
Feet.	*Inches.*	*Inches.*	*Sq. in.*			
2	$4\frac{1}{2}$	6	0.250	$\frac{3}{8}$ inch @ 7 inches[2]	$\frac{3}{8}$ inch @ 6 inches[2]	1–$\frac{3}{8}$ inch.[3]
3	$4\frac{1}{2}$	6	.307	$\frac{3}{8}$ inch @ $5\frac{1}{2}$ inches[2]	$\frac{1}{2}$ inch @ $7\frac{1}{2}$ inches[2]	2–$\frac{3}{8}$ inch.[3]
4	6	$7\frac{1}{2}$	.436	$\frac{1}{2}$ inch @ $6\frac{1}{2}$ inches[2]	$\frac{1}{2}$ inch @ 5 inches.[2]	3–$\frac{3}{8}$ inch.[3]
5	$7\frac{1}{2}$	9	.549	$\frac{1}{2}$ inch @ $5\frac{1}{2}$ inches[2]	$\frac{5}{8}$ inch @ $6\frac{1}{2}$ inches[2]	4–$\frac{1}{2}$ inch.[3]
6	$9\frac{1}{2}$	11	.659	$\frac{5}{8}$ inch @ 7 inches	$\frac{5}{8}$ inch @ $5\frac{1}{2}$ inches[2]	5–$\frac{1}{2}$ inch.[3]

[1] For intermediate spacings, dimensions and area of steel may be obtained by interpolation.
[2] Center to center.
[3] Round rods between beams.

The computations were based on a live load of 15 tons concentrated on two axles 8 feet apart with two-thirds of the weight on the rear axle, and the wheels spaced 6 feet center to center on the axles. Each wheel load was assumed to be distributed by the cushion and slab over an area 3 feet in the direction of traffic by 5 feet at right angles to that direction. The distribution in the direction of traffic was neglected, however, in making computations for the beams. Allowances for an impact of 50 per cent of the live load and 25 per cent of the live load were made, respectively, for the slabs and beams.

Plate VIII shows a typical design for a T-beam bridge having a clear span of 20 feet and a width of roadway of 24 feet.

INCASED I-BEAM SUPERSTRUCTURES.

Steel I beams incased in concrete are frequently substituted for the reinforced T beams just described. The I beams are designed to carry the entire load and the concrete which incases them is intended only as a protection against corrosion.

The principal advantages to be gained by using this type are the ease with which the forms may be constructed and an additional factor of safety in case of unequal settlement of the abutments. The only disadvantage is in point of economy.

Table 13, for use in designing I-beam superstructures, covers the same range of spans as those for the T beams. The proper spacing to be selected in any individual case depends on much the same considerations as those which govern the spacing of the T beams.

The assumptions as to loading are the same as for the T beams, with the exception that no allowance is made for the effect of impact on the I beams.

Plate IX shows a typical I-beam bridge for a span of 18 feet and a width of roadway of 24 feet.

TABLE 13.—*Data for use in designing I-beam superstructures.*

Span.	Standard I-beam.	Maximum allowable spacing.	Span.	Standard I-beam.	Maximum allowable spacing.
Feet.	*In. Lbs.*	*Ft. in.*	*Feet.*	*In. Lbs.*	*Ft. in.*
	8 18	2 3		15 42	2 6
10	9 21	3 0	22	18 55	3 10
	10 25	3 10		20 65	4 10
	9 21	2 4		15 42	2 1
12	10 25	3 1	24	18 55	3 3
	12 31.5	4 3		20 65	4 3
	10 25	2 4		18 55	2 9
14	12 31.5	3 4	26	20 65	3 8
	15 42	5 4		24 80	5 3
	12 31.5	2 9		18 55	2 4
16	15 42	4 5	28	20 65	3 2
	18 55	6 0		24 80	4 7
	12 31.5	2 2		18 55	2 0
18	15 42	3 6	30	20 65	2 10
	18 55	5 3		24 80	4 0
	15 42	3 0			
20	18 55	4 5			
	20 65	5 7			

TYPICAL DETAILS.

RAILINGS.

Figure 1 shows a typical reinforced concrete railing, suitable for either slab or T-beam bridges. The same dimensions may be used

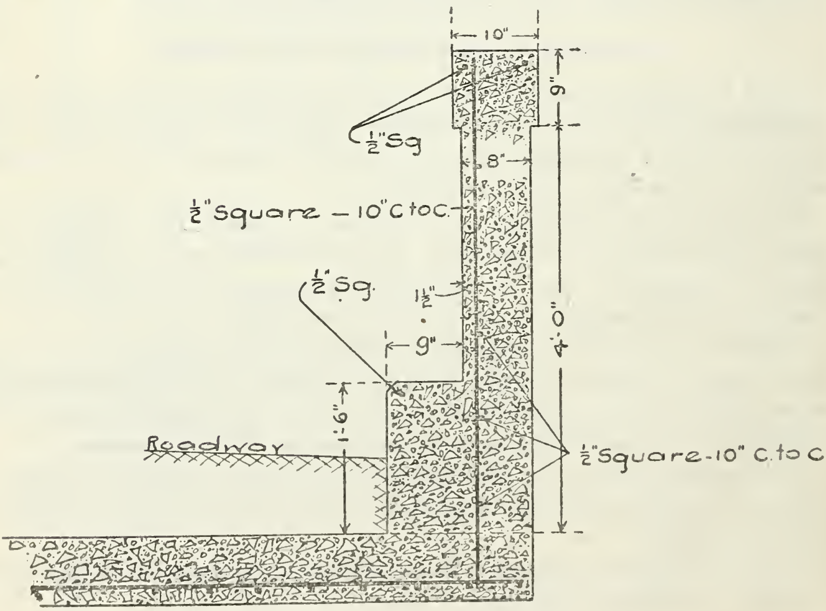


FIG. 1.—Reinforced-concrete railing.

for all spans, but the appearance of the longer spans may be improved by increasing all dimensions of the railing in the same proportion. The amount of reinforcing steel, however, should not be changed.

With the dimensions shown, the quantities of materials may be estimated as follows: Concrete per linear foot (2 railings), 0.327 cubic yard; and steel per linear foot (2 railings), 24 pounds.

Pipe railing is also frequently used. It should be made from gas pipe not less than 2 inches in diameter. Plate X shows a typical design.

END AND WING WALLS.

These are designed as retaining walls and may be built of either plain or reinforced concrete. Where broken stone and sand are to be readily and inexpensively obtained, plain concrete is the cheaper, but where these have to be shipped in or hauled from a considerable distance the reinforced type is usually the more economical.

Figure 2 shows a plain concrete section suitable for either end or wing walls. Under the conditions ordinarily encountered in the construction of highway culverts and short-span bridges this section may be safely proportioned as follows:

$W = \frac{H}{12}$ (never less than 10 inches).

$b = \frac{4}{10} H$ (never less than 10 inches).

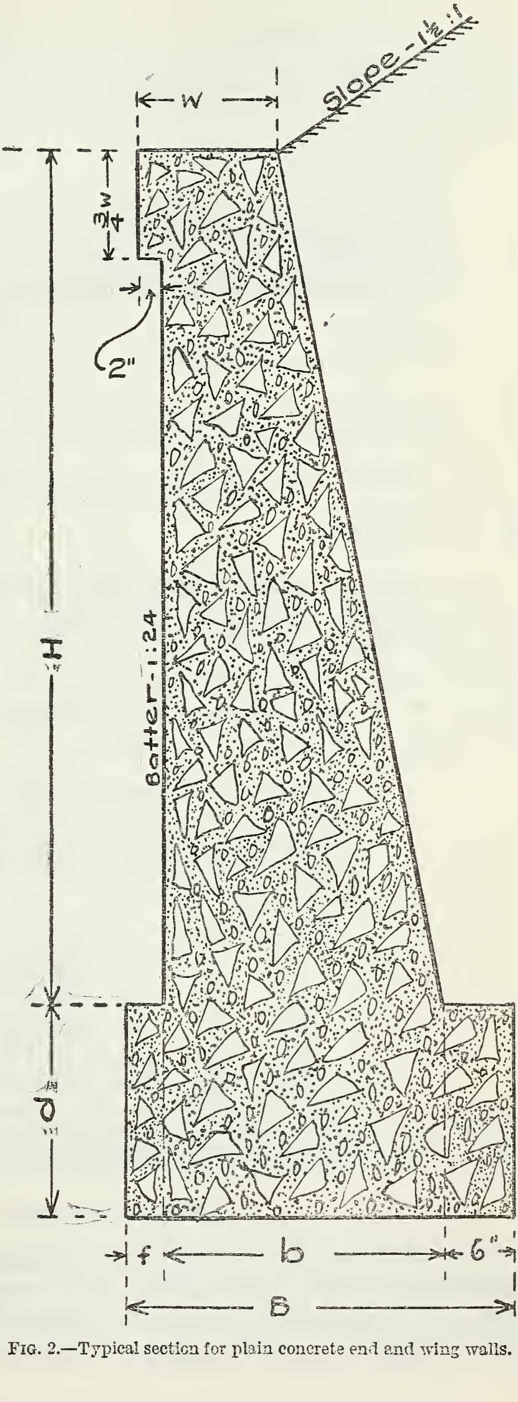


FIG. 2.—Typical section for plain concrete end and wing walls.

$$d=\frac{H}{12}+12 \text{ inches.}$$

$$f=B-b-6 \text{ inches.}$$

B varies with the character of the foundation material.

For walls over 6 feet high the following values may be used:

For rock foundation	$B=\frac{4}{10}\ \mathrm{H}+9$ inches.
For good gravel foundation	$B=\frac{4}{10}\ H+12$ inches.
For medium gravel foundation	$B=\frac{4}{10}\ H+15$ inches.
For good clay foundation	$B=\frac{4}{10}\ H+18$ inches.
For medium clay foundation	$B=\frac{4}{10}\ H+21$ inches.

For walls less than 6 feet high, B need never be greater than $\frac{4}{10}\ H+12$ inches.

For reinforced end and wing walls the section shown in Plate XI is well adapted. The proportions shown may be safely used within reasonable limits, but for very high walls it is usually wise to make a special design, taking all the local conditions into consideration. Values of W and directions for reinforcing are given in Table 14 for heights ranging from 2 to 20 feet.

TABLE 14.—*Reinforcement of end and wing walls.*

Height of wall (H).	Top thickness (W).	Area of steel required.	Size and spacing of vertical reinforcing rods (center to center).
Feet.	*Inches.*	*Sq. in.*	
2	7	....	½ inch square @ 12 inches.
4	7	....	½ inch square @ 12 inches.
6	7	....	½ inch square @ 12 inches.
8	8	0.23	½ inch square @ 10 inches.
10	9	.36	½ inch square @ 8 inches.
12	10	.56	⅝ inch square @ 8 inches.
14	12	.73	⅝ inch square @ 6 inches.[1]
16	12	1.02	¾ inch square @ 6 inches.[1]
18	14	1.30	¾ inch square @ 5 inches.[2]
20	16	1.60	¾ inch square @ 4 inches.[3]

[1] Alternate rods to end at 8 feet up from base.
[2] Alternate rods to end at 9 feet up from base.
[3] One-third of rods to end at 4 feet and ⅓ at 10 feet up from base.

ABUTMENT WALLS.

Plate XII and figure 3 represent abutments of plain concrete and reinforced concrete respectively. In the case of slab superstructures either type may be used and the selection for any particular case should depend on considerations of economy. The conditions which

affect the cost are much the same as those outlined under the section on end and wing walls.

Where the superstructure is to be of the T-beam type, however, the massiveness of the plain abutment enables it to furnish a more stable anchorage for the beams and gives it advantages over the reinforced type in the matter of construction. Moreover, for T-beam superstructures the plain abutment is usually the more economical.

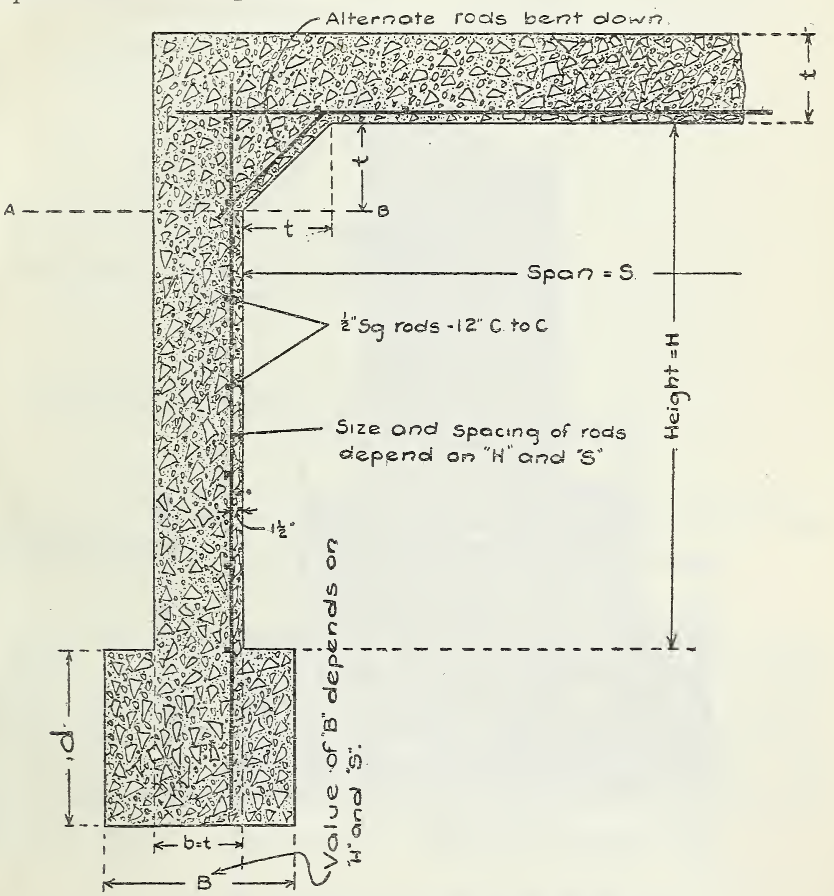


FIG. 3.—Typical section for a reinforced-concrete abutment wall.

The data given below for use in designing reinforced abutments have, therefore, been made applicable for use only with the slab superstructure.

REINFORCED CONCRETE.

In figure 3 the thickness of the abutment wall is shown to be the same as that of the slab. Where the height of the wall, however, exceeds the span of the bridge or culvert, it should be given a slight batter on the back, so that the thickness at the middle point will be

no less than that of a slab designed for a span equal in length to the height of the wall. Under no circumstances should the thickness of the wall be made less than that of the slab.

In computing the amount of vertical reinforcement, as given in Table 15, it has been assumed that the wall sustains a uniform load equal to that carried by the slab and acts as a simple beam supported

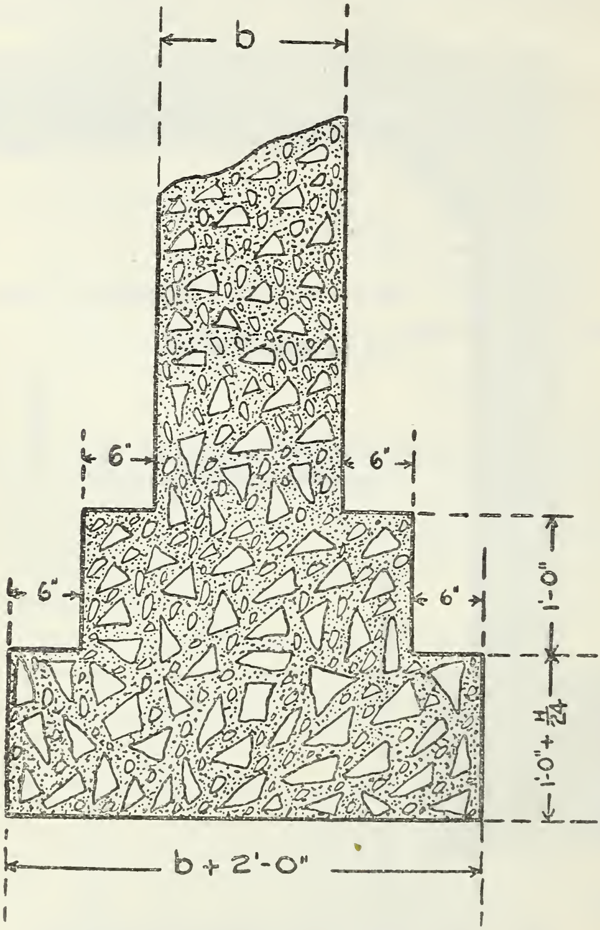


FIG. 4.—Double footing for a reinforced-concrete abutment wall.

at the ends. If the footing is securely bedded, this assumption is sufficiently severe to provide for any reasonable condition of back filling.

Table 15 gives the area of vertical reinforcement required in a 1-foot strip of the wall and suggestions as to size and spacing of rods for various heights and spans. For intermediate heights of wall the area of steel may be obtained from this table with sufficient accuracy by means of interpolation.

The prime requirement for reinforced concrete abutment footings is that they shall be well bedded in the foundation material and be thoroughly protected from undermining by currents of water. Footings must also be proportioned to take care of the loads which they will be required to sustain. The following formulæ are suggested as giving practical results for spans up to 16 feet:

Let

t = thickness of slab;

s = span;

H = height of opening;

b = thickness of abutment wall at the top of the footing;

B = width of footing; and

d = depth of footing.

In the same units, then

$b = t$ (where s is greater than H).

For spans of from 2 to 8 feet

$B = b + 12$ inches; and

$$d = 18'' + \frac{H}{24}.$$

For spans of from 9 to 12 feet

$B = b + 16$ inches; and

$$d = 21'' + \frac{H}{24}.$$

For spans of from 13 to 16 feet two steps should be used in footings, and they should be dimensioned as shown in figure 4.

PLAIN CONCRETE.

Table 16 gives suitable dimensions for plain concrete abutment walls of cross section, such as is shown in Plate XII, for various heights and spans. The footings are proportioned for clay or gravel foundations. For rock foundations it will ordinarily be sufficient to let the footing project about 4 inches on each side of the wall. The footing should always be protected against undermining by currents of water.

TABLE 15.—*Reinforced abutment walls—Directions for reinforcing.*

Height: 4 feet and 6 feet.

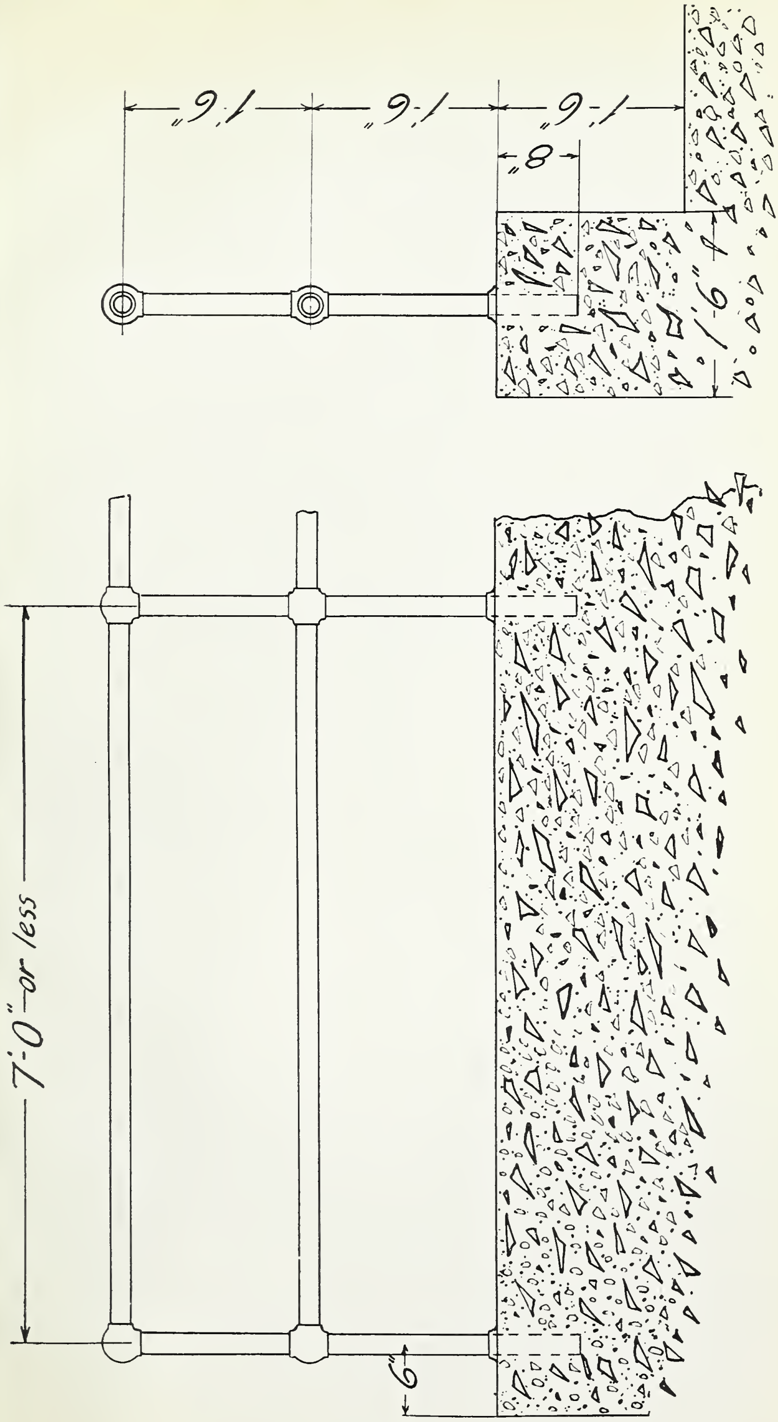
Span.	4 feet. Area of steel in a 1-foot strip.	4 feet. Square rods. Size.	4 feet. Square rods. Spacing, center to center.	4 feet. Round rods. Size.	4 feet. Round rods. Spacing, center to center.	6 feet. Area of steel in a 1-foot strip.	6 feet. Square rods. Size.	6 feet. Square rods. Spacing, center to center.	6 feet. Round rods. Size.	6 feet. Round rods. Spacing, center to center.
Ft.	*Sq. in.*	*Inch.*	*In.*	*Inch.*	*In.*	*Sq. in.*	*Inch.*	*In.*	*Inch.*	*In.*
2	0.523	½	5½	⅝	7	0.653	⅝	7	¾	8
3	.523	½	5½	⅝	7	.653	⅝	7	¾	8
4	.523	½	5½	⅝	7	.653	⅝	7	¾	8
5	.486	½	5¾	⅝	7	.653	⅝	7	¾	8
6	.446	½	6½	⅝	8	.653	⅝	7	¾	8
7	.416	½	7	⅝	8½	.610	⅝	7½	¾	8½
8	.364	½	8	⅝	10	.535	½	5½	⅝	6¾
9	.324	½	9	⅝	11	.475	½	6	⅝	7½
10	.308	½	9½	⅝	12	.450	½	6½	⅝	8
11	.292	½	10	⅝	12	.425	½	7	⅝	8½
12	.280	½	10	⅝	12	.408	½	7½	⅝	9
13	......	½	12	⅝	12	.372	½	8	⅝	10
14	......	½	12	½	12	.342	½	8½	⅝	10¾
15	......	½	12	½	12	.327	½	9	⅝	11
16	......	½	12	½	12	......	½	10	⅝	12

Height: 8 feet.

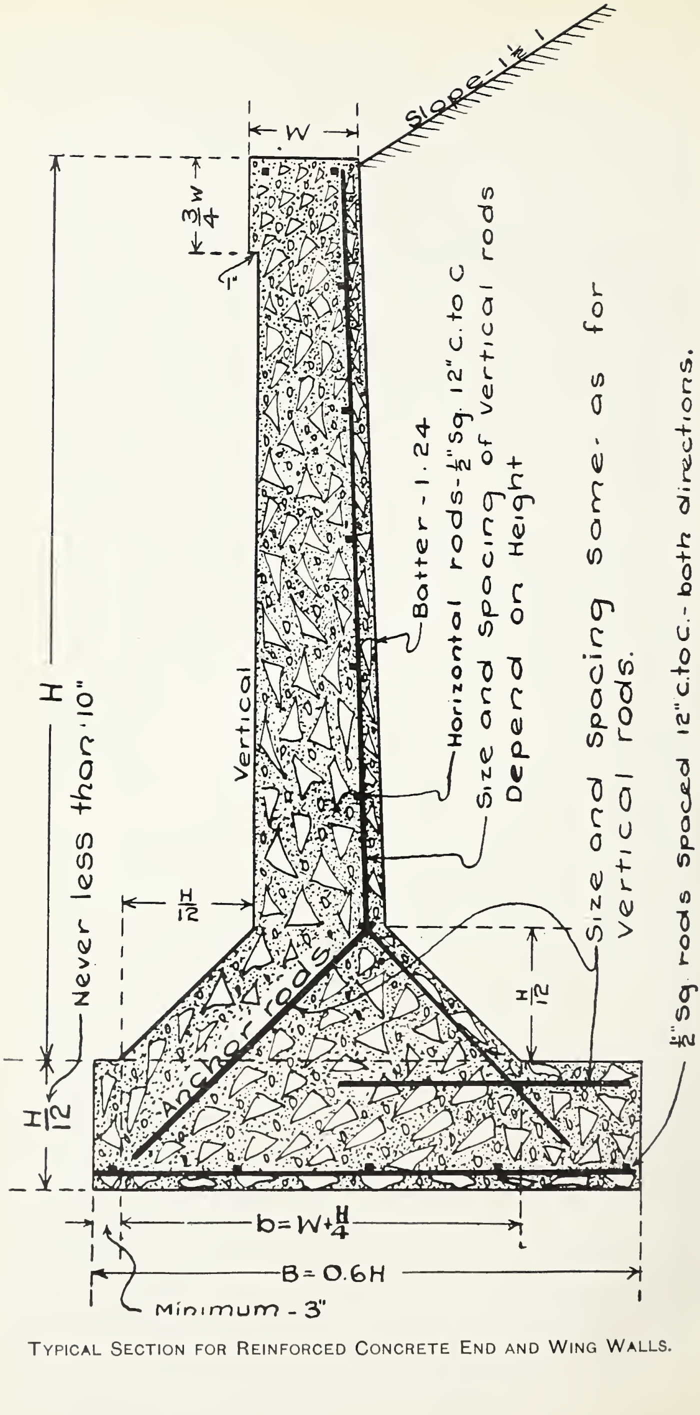
Span.	8 feet. Area of steel in a 1-foot strip.	8 feet. Square rods. Size.	8 feet. Square rods. Spacing, center to center.	8 feet. Round rods. Size.	8 feet. Round rods. Spacing, center to center.
Ft.	*Sq. in.*	*Inch.*	*In.*	*Inch.*	*In.*
2	......	......	......	......	......
3	......	......	......	......	......
4	0.810	⅝	5¾	¾	6½
5	.810	⅝	5¾	¾	6½
6	.810	⅝	5¾	¾	6½
7	.810	⅝	5¾	¾	6½
8	.810	⅝	5¾	¾	6½
9	.720	⅝	6½	¾	7
10	.684	⅝	7	¾	7½
11	.648	⅝	7	¾	8
12	.618	⅝	7½	¾	8½
13	.560	½	5½	⅝	6½
14	.520	½	5¾	⅝	7
15	.497	½	6	⅝	7½
16	.462	½	6	⅝	8

Height: 12 feet and 16 feet.

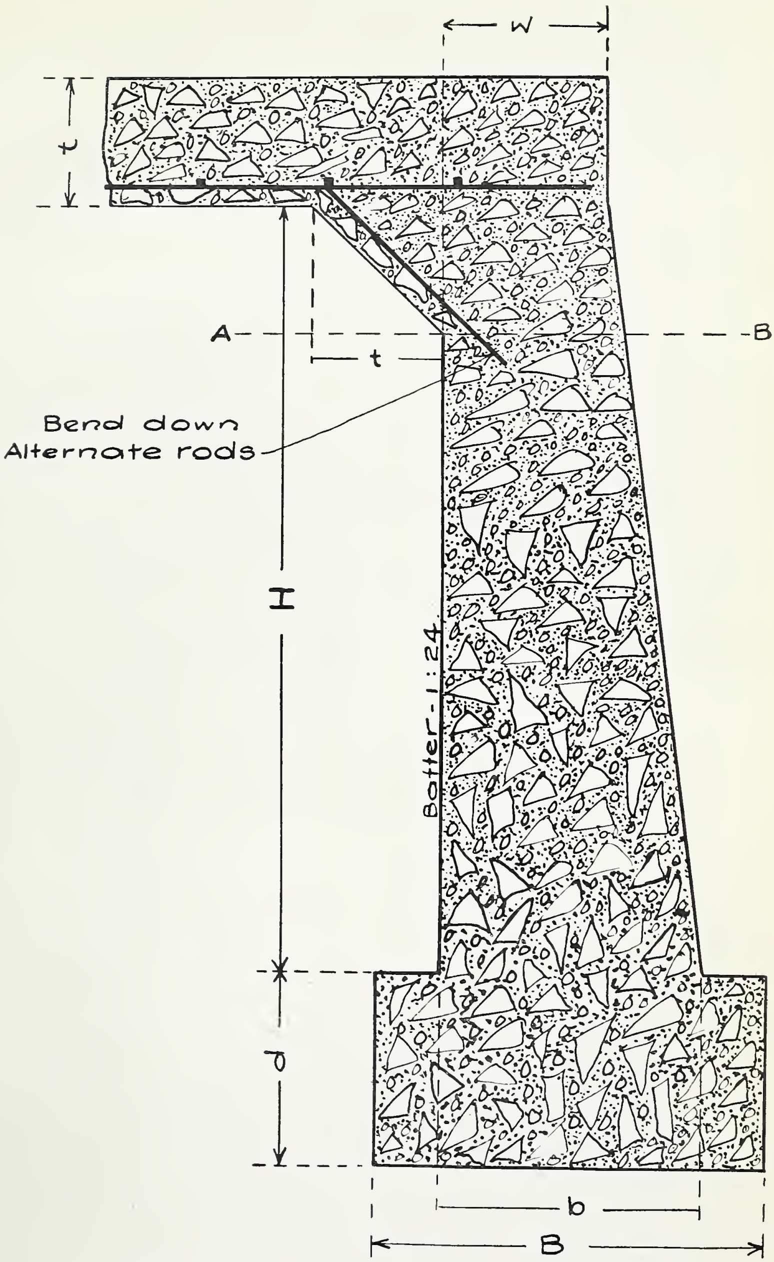
Span.	12 feet. Area of steel in a 1-foot strip.	12 feet. Square rods. Size.	12 feet. Square rods. Spacing, center to center.	12 feet. Round rods. Size.	12 feet. Round rods. Spacing, center to center.	16 feet. Area of steel in a 1-foot strip.	16 feet. Square rods. Size.	16 feet. Square rods. Spacing, center to center.	16 feet. Round rods. Size.	16 feet. Round rods. Spacing, center to center.
Ft.	*Sq. in.*	*Inch.*	*In.*	*Inch.*	*In.*	*Sq. in.*	*Inch.*	*In.*	*Inch.*	*In.*
2	......	......	......	......	......	......	......	......	......	......
3	......	......	......	......	......	......	......	......	......	......
4	......	......	......	......	......	......	......	......	......	......
5	......	......	......	......	......	......	......	......	......	......
6	......	......	......	......	......	......	......	......	......	......
7	......	......	......	......	......	......	......	......	......	......
8	1.062	¾	6¼	⅞	6¾	......	......	......	......	......
9	1.062	¾	6¼	⅞	6¾	......	......	......	......	......
10	1.062	¾	6¼	⅞	6¾	......	......	......	......	......
11	1.062	¾	6¼	⅞	6¾	......	......	......	......	......
12	1.062	¾	6¼	⅞	6¾	1.350	¾	5	⅞	5¼
13	.982	¾	6¾	⅞	7¼	1.350	¾	5	⅞	5¼
14	.893	¾	7½	⅞	8	1.350	¾	5	⅞	5¼
15	.852	¾	8	⅞	8½	1.350	¾	5	⅞	5¼
16	.800	¾	8½	⅞	9	1.350	¾	5	⅞	5¼



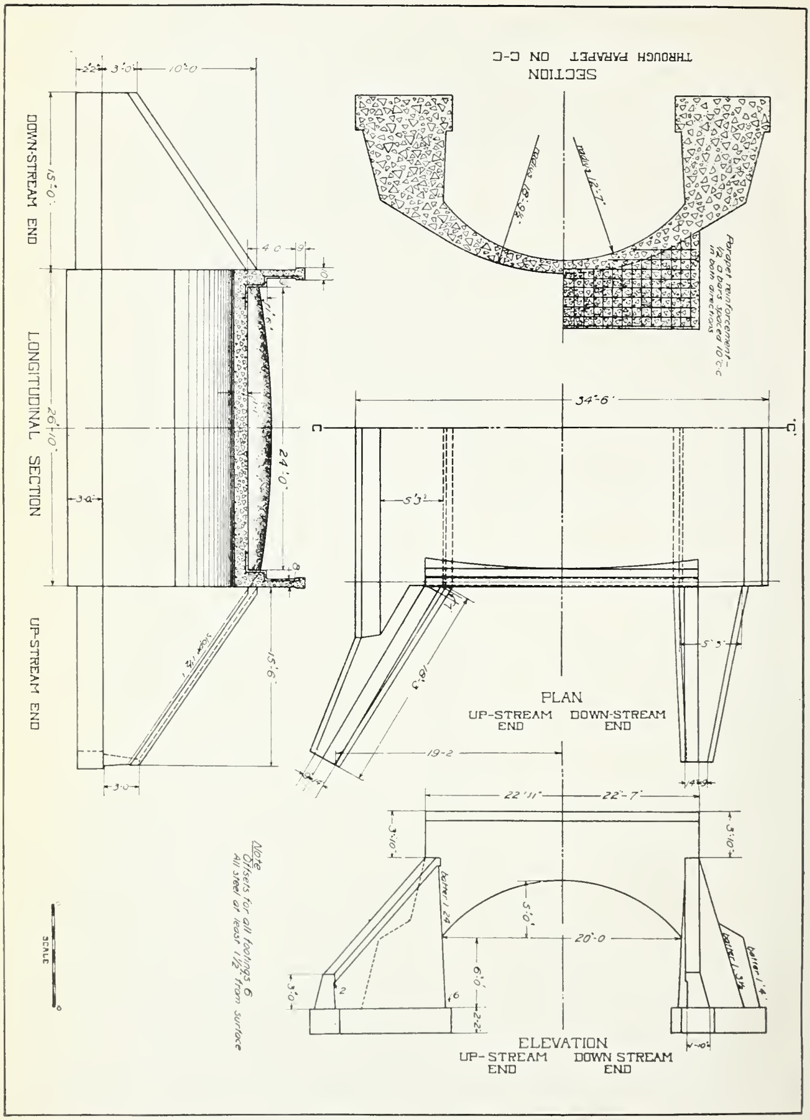
PIPE RAILING.



Typical Section for Reinforced Concrete End and Wing Walls.



TYPICAL SECTION FOR A PLAIN CONCRETE ABUTMENT WALL.



PLAN FOR A PLAIN CONCRETE ARCH CULVERT.

TABLE 16.—*Dimensions for plain concrete abutment walls.*

Span.	Top thickness.	Heights of opening. 4 feet. Base (b).	4 feet. Footing ($B \times d$).	6 feet. Base (b).	6 feet. Footing ($B \times d$).	8 feet. Base (b).	8 feet. Footing ($B \times d$).	10 feet. Base (b).	10 feet. Footing ($B \times d$).	12 feet. Base (b).	12 feet. Footing ($B \times d$).	14 feet. Base (b).	14 feet. Footing ($B \times d$).	16 feet. Base (b).	16 feet. Footing ($B \times d$).	18 feet. Base (b).	18 feet. Footing ($B \times d$).	20 feet. Base (b).	20 feet. Footing ($B \times d$).
Feet.	*Inches.*	*In.*	*Inches.*	*In.*	*Inches.*	*In.*	*Inches.*	*In.*	*Inches.*	*In.*	*Inches.*	*In.*	*Inches.*	*In.*	*Inches.*	*In.*	*Inches.*	*Inches.*	*Inches.*
4	10	20	28 by 18	24	36 by 18	......	......	......	......	......	......	......	......	......	......	......	......	......	......
5	10	20	28 by 18	24	36 by 18	......	......	......	......	......	......	......	......	......	......	......	......	......	......
6	12	20	28 by 18	24	36 by 18	32	44 by 18	......	......	......	......	......	......	......	......	......	......	......	......
7	12	20	28 by 18	24	36 by 18	32	44 by 18	......	......	......	......	......	......	......	......	......	......	......	......
8	13	22	30 by 18	26	38 by 18	36	48 by 18	44	56 by 20	......	......	......	......	......	......	......	......	......	......
9	14	22	30 by 18	26	38 by 18	36	48 by 18	44	56 by 20	......	......	......	......	......	......	......	......	......	......
10	14	22	30 by 18	26	38 by 18	36	48 by 18	44	56 by 20	52	64 by 20	......	......	......	......	......	......	......	......
11	15	22	30 by 18	26	38 by 18	36	48 by 18	44	56 by 20	52	64 by 20	......	......	......	......	......	......	......	......
12	16	24	32 by 18	28	40 by 18	38	50 by 20	48	60 by 22	58	70 by 22	68	82 by 22	......	......	......	......	......	......
13	17	24	32 by 18	28	40 by 18	38	50 by 20	48	60 by 22	58	70 by 22	68	82 by 22	......	......	......	......	......	......
14	17	24	32 by 18	28	40 by 18	38	50 by 20	48	60 by 22	58	70 by 22	68	82 by 22	78	92 by 24	......	......	......	......
15	18	24	32 by 18	28	40 by 18	38	50 by 20	48	60 by 22	58	70 by 22	68	82 by 22	78	92 by 24	......	......	......	......
16	18	26	34 by 18	30	42 by 20	40	52 by 20	50	64 by 22	62	76 by 22	72	86 by 24	82	98 by 24	92	108 by 24	......	......
18	20	26	34 by 18	30	42 by 20	40	52 by 20	50	64 by 22	62	76 by 22	72	86 by 24	82	98 by 24	92	108 by 24	......	......
20	22	26	34 by 18	30	42 by 20	40	52 by 20	50	64 by 22	62	76 by 22	72	86 by 24	82	98 by 24	92	103 by 24	102	120 by 26
22	24	28	36 by 18	30	42 by 20	40	52 by 20	50	64 by 22	62	76 by 22	72	86 by 24	82	98 by 24	92	103 by 24	102	120 by 26
24	25	28	36 by 18	32	46 by 20	42	56 by 22	52	66 by 24	66	80 by 24	76	92 by 24	86	102 by 26	98	116 by 26	108	126 by 28
26	26	28	36 by 18	32	46 by 20	42	56 by 22	52	66 by 24	66	80 by 24	76	92 by 24	86	102 by 26	98	116 by 26	108	126 by 28
28	27	30	38 by 18	32	46 by 20	42	56 by 22	52	66 by 24	66	80 by 24	76	92 by 24	86	102 by 26	98	116 by 26	108	126 by 28
30	28	30	38 by 18	32	46 by 20	42	56 by 22	52	66 by 24	66	80 by 24	76	92 by 24	86	102 by 26	98	116 by 26	108	126 by 28

ARCH BRIDGES AND CULVERTS.

For locations where sufficient "head room" and an unyielding foundation may be obtained the arch type of construction is admirably adapted. Properly designed arches not only present a pleasing appearance, but under favorable conditions frequently offer advantages over other types of construction in point of economy.

Arches may be constructed of brick, stone, plain concrete, reinforced concrete, or steel. For arches so designed that any load to be sustained by the structure will produce only compression in the arch ring, some one of the first three materials may preferably be used. Where the combined action of the dead and live loads would produce a resultant tension at some point in the arch ring, however, it becomes necessary to use either reinforced concrete or steel.

For the shorter spans, such as are being here considered, it is usually economical so to proportion the arch ring that it will be required to withstand only compression. Most short-span arch bridges and culverts have therefore been constructed of brick, stone, or plain concrete. On account of its cheapness and simplicity of construction the concrete arch is now being much more generally used than either of the other types.

Table 17 (data on plain concrete circular arches) has been computed from empirical formulas based on existing arches which have proved satisfactory under modern traffic conditions, and Plate XIII shows a typical design. The wing walls, parapets, railings, etc., may be dimensioned from data given under the section on typical details.

In the construction of concrete arches special care should be given to mixing and depositing the concrete, as imperfections in any part of the arch ring are likely to prove disastrous.

TABLE 17.—*Data on plain concrete circular arches.*

Span.	Minimum rise.	Crown thickness.	Radial thickness of arch at springing.	Abutment thickness at springing.	Batter back of abutment.	Batter front of abutment throughout.	Offset for footing front and back throughout.
Feet.	*Ft. in.*	*Ft. in.*	*Ft. in.*	*Ft. in.*			*Inches.*
3	1 6	0 5	1 0	1 0	1 : 12		
4	2 0	0 5	1 0	1 0	1 : 12		
5	2 0	0 6	1 3	1 6	1 : 9		
6	2 0	0 6	1 3	2 0	1 : 9		
7	2 0	0 7	1 6	2 3	1 : 6		
8	2 0	0 7	1 6	2 6	1 : 6		
9	2 3	0 8	1 8	2 9	1 : 6		
10	2 6	0 8	1 8	3 0	1 : 6		
12	3 0	0 9	1 11	3 6	1 : 6	1 : 24	6
14	3 6	0 10	2 1	4 0	1 : 6		
16	4 0	0 11	2 4	4 6	1 : 4		
18	4 6	1 0	2 6	5 0	1 : 4		
20	5 0	1 1	2 9	5 3	1 : 4		
22	5 6	1 2	2 11	5 5	1 : 4		
24	6 0	1 3	3 1	5 6	1 : 3		
26	6 6	1 4	3 4	5 8	1 : 3		
28	7 0	1 5	3 7	5 10	1 : 3		
30	7 6	1 6	3 9	6 0	1 : 3		

TYPICAL SPECIFICATIONS FOR REINFORCED CONCRETE BRIDGE AND CULVERT CONSTRUCTION.

PLANS AND DRAWINGS.

All concrete masonry shall be built to conform with the lines and dimensions shown on the plans and drawings furnished or approved by the engineer in charge, and which are hereby made a part of these specifications. In cases of discrepancies between figured dimensions and scale, the figured dimensions are to govern.

CONCRETE.

The concrete shall be of the character and mixed in the proportion indicated on the plans, or as may be indicated in writing by the engineer in charge, or as hereinafter specified. All concrete shall be prepared and placed in strict accordance with the following specifications and plans, and the instructions of the engineer under them.

CEMENT.

The cement shall be of some standard brand of Portland cement, satisfactory to the engineer in charge. No cement shall be used which, when tested, fails to conform with the United States Government specifications for Portland cement, as contained in Circular 33 of the Bureau of Standards. Cement shall be delivered in sacks of 94 pounds net weight, and each sack shall be considered as having a volume of 1 cubic foot. Cement which contains lumps or has been damaged in any way by exposure to the weather or by other cause shall be rejected.

SAND.

The sand shall consist of dry, clean, sharp quartz grains and shall not contain more than 5 per cent of clay, loam, or other foreign materials. The grains shall be well graded and of such size that all will pass a $\frac{1}{4}$-inch mesh screen, and not more than 20 per cent will pass a No. 50 sieve.

COARSE AGGREGATE.

The coarse aggregate may consist of either broken stone or gravel. Stone shall be sound, hard, and tough, and broken to the sizes hereinafter specified, and when used shall be free from foreign material. No weathered or disintegrated material shall be used. Gravel shall be composed of hard, sound, durable particles of stone, thoroughly clean and well graded in size between the limits specified below.

Classes A, B, and C.—Unless otherwise specially provided, there shall be three classes of concrete, known as class A, class B, and class C.

Class A concrete shall consist (by volume) of 1 part of cement, 2 parts of sand, 4 parts of coarse aggregate, and water. All of the coarse aggregate shall be retained on a $\frac{1}{4}$-inch mesh screen and shall pass a 1-inch mesh screen. Not more than 75 per cent shall be retained on a $\frac{1}{2}$-inch mesh screen and not more than 75 per cent shall pass such a screen.

Class B concrete shall consist (by volume) of 1 part of cement, $2\frac{1}{2}$ parts of sand, 5 parts of coarse aggregate, and water. All of the coarse aggregate shall be retained on a $\frac{1}{4}$-inch mesh screen and shall pass a $1\frac{1}{2}$-inch mesh screen. Not more than 75 per cent shall be retained on a $\frac{3}{4}$-inch mesh screen and not more than 75 per cent shall pass such a screen.

Class C concrete shall consist (by volume) of 1 part of cement, 3 parts of sand, 6 parts of coarse aggregate, and water. All of the coarse aggregate shall be retained on a $\frac{1}{4}$-inch mesh screen and shall pass a $2\frac{1}{2}$-inch mesh screen. Not more than 75 per cent shall be retained on a $1\frac{1}{4}$-inch mesh screen and not more than 75 per cent shall pass such a screen.

MIXING.

The cement and sand shall first be thoroughly mixed dry in the proportions specified, on a proper mixing platform. Sufficient clean water shall then be admixed to produce a pasty mortar. To the mortar thus prepared shall be added the proper proportion of coarse aggregate previously drenched with water, and the whole shall be mixed until every particle of the coarse aggregate is thoroughly coated with mortar. Instead of the above method, a mechanical mixer of approved type may be employed.

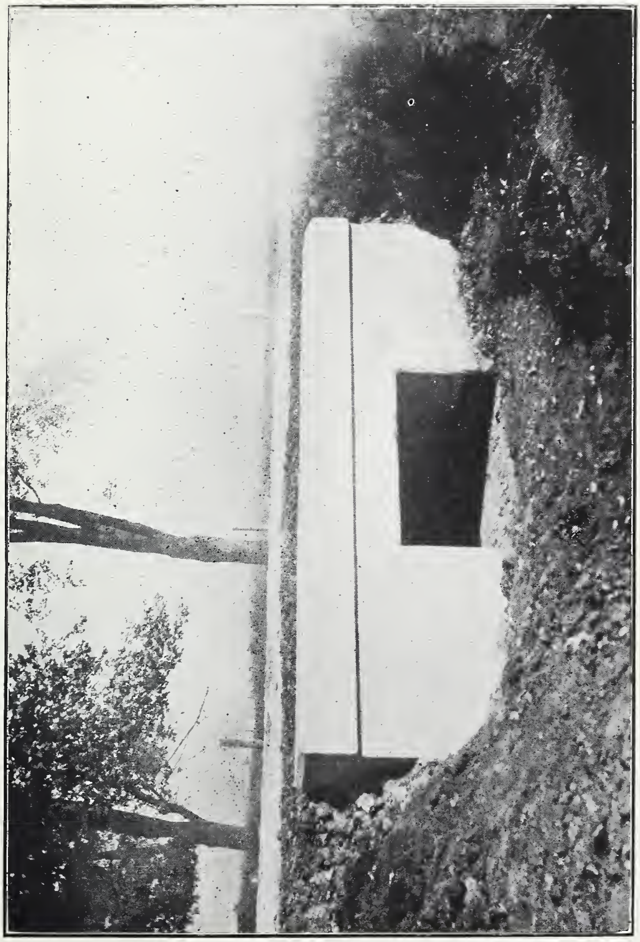
SIZE OF BATCH.

Concrete shall be mixed in batches of such size that the entire batch may be placed in the forms by the force employed within 45 minutes from the time that the first water is applied. No concrete is to be prepared from mortar which has taken an initial set and would require retempering.

PLACING.

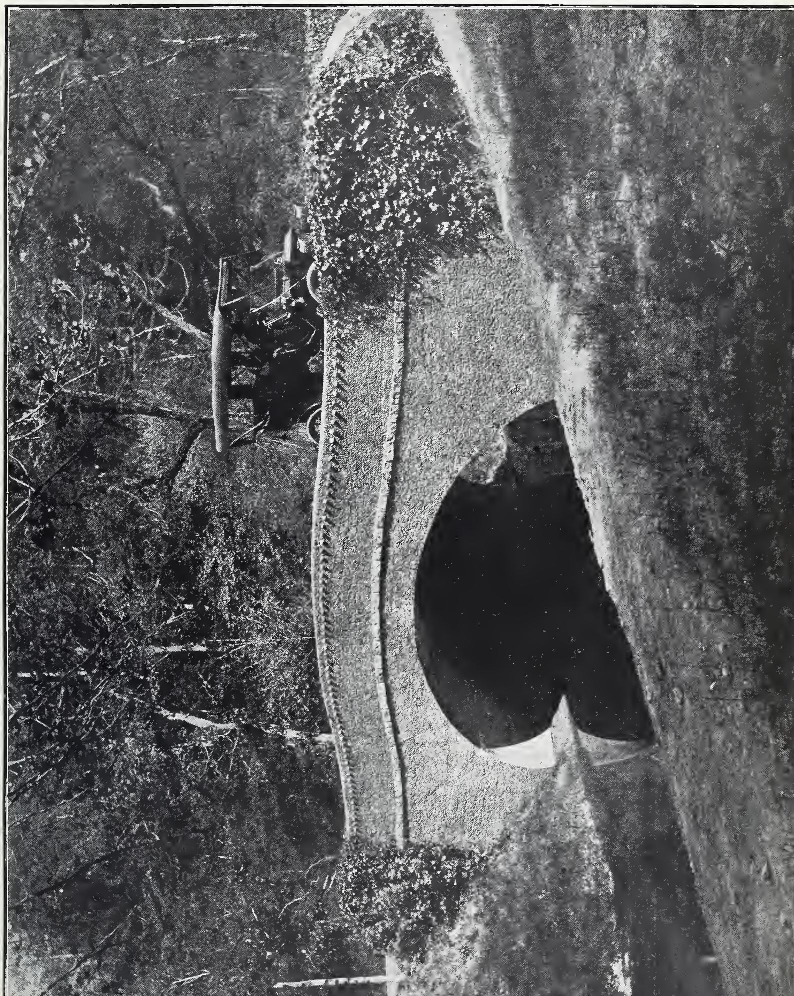
All concrete shall be carefully deposited in place and never allowed to fall from a height greater than five feet. Concrete shall never be deposited in running water, and when deposited in still water it shall be carefully lowered into place by means of a chute or by some other approved method.

As fast as concrete is put into place, it shall be thoroughly tamped in layers not more than six inches thick, and the portion next to the forms shall be troweled by using a spade or by other means to bring the mortar into thorough contact with the forms.



REINFORCED CONCRETE BOX CULVERT IN WISCONSIN.

STONE ARCH BRIDGE IN THE DISTRICT OF COLUMBIA.



CONCRETE ARCH BRIDGE IN THE DISTRICT OF COLUMBIA.

Concrete shall not be deposited when the temperature of any of the materials composing it is below 35° F., and if during the progress of the work freezing temperature threatens or is predicted by the United States Weather Bureau, proper precautions shall be taken to protect from freezing all concrete laid within the four preceding days.

FORMS.

Forms shall be so constructed as to continue rigidly in place during and after depositing and tamping the concrete. If during the placing of the concrete the forms show signs of bulging or sagging at any point, that portion of the concrete causing the distortion shall be immediately removed and the forms properly supported before continuing the work. The amount of concrete to be removed shall be determined by the engineer, and the contractor shall receive no extra compensation on account of the extra work thus occasioned. Forms for exposed surfaces shall be constructed of dressed lumber.

All forms shall be left in place not less than 36 hours and all supporting forms not less than 10 days after the concrete has been deposited. These periods may be increased at the discretion of the engineer in charge.

It is understood that all prices for concrete masonry shall include furnishing all materials and properly constructing all necessary forms.

JOINTS.

When the work of laying concrete is to be interrupted for a period greater than 1 hour and there are no reinforcing rods projecting, provision for a joint shall be made in the following manner: Square timbers 8 inches by 8 inches, or some other suitable size approved by the engineer, shall be bedded in the concrete throughout the length of the course for one-half their thickness and allowed to remain until the concrete has taken its initial set. When the work of laying concrete is resumed, the timbers shall be removed and the surface thoroughly wet. No joints will be permitted in reinforced-concrete beams, and in floor slabs the joints shall be vertical and parallel to the main reinforcing bars.

FINISH.

Forms covering surfaces of the concrete masonry which are to be exposed shall be removed immediately after the expiration of the period of time necessary for such forms to remain in place, as fixed by the engineer, and all crevices which may appear shall be filled with 1 : 2 cement mortar. These surfaces shall then be finished with 1 : 2 cement-mortar and a wooden float, so as to present a smooth, neat appearance.

REINFORCED CONCRETE.

All reinforced arches, beams, floors, parapets, guard rails, and all concrete masonry measuring less than 9 inches in thickness shall be made of class A concrete, unless otherwise specified on the drawings or directed by the engineer in writing.

ABUTMENTS AND WING WALLS.

Unless otherwise specified on the drawings or in writing by the engineer, class B concrete shall be used for all abutments and wing walls the thickness of which is not less than 9 inches.

FOOTINGS AND CUT-OFF WALLS.

Class C concrete shall be used for all footings and cut-off walls, unless otherwise specified on the plans or directed in writing by the engineer.

STEEL FOR REINFORCED CONCRETE.

Unless otherwise specified on the drawings, all reinforcing steel shall consist of bars which have been deformed in some approved manner. No plain bars will be permitted except as shown on the drawings or directed in writing by the engineer.

The steel bars shall have the net sectional area and be placed in the exact positions indicated on the drawings.

Unless otherwise specified on the drawings or in writing by the engineer, all reinforcing bars shall be of medium steel having an elastic limit of not less than 35,000 pounds per square inch, and shall be sufficiently malleable to withstand bending cold with a radius equal to twice the diameter or thickness of the bar through 180° without fracture.

When placed in the concrete, the reinforcing steel shall be free from grease, dirt, and rust, and it shall be the duty of the contractor to provide means for properly cleaning the steel.

Thorough contact of the concrete with every portion of the surface of the steel shall be obtained.

SPLICING REINFORCING BARS.

Unless otherwise specified on the drawings or in writing by the engineer, necessary splices in reinforcicg bars shall be effected by overlapping the ends of the bars a distance equal to forty times their thickness or diameter.

CONCLUSION.

Designers of highway bridge and drainage structures are urged not only to investigate the safety and durability of proposed designs, but to consider their aesthetic features as well. When

bridges and culverts are to be constructed of permanent materials, such as reinforced concrete, the designer should bear constantly in mind the fact that any aesthetic defects which may be present in such structures will become more and more apparent as the community develops. For example, a highway bridge the defects of which are hardly noticeable when the highway on each side is bordered by dilapidated fences and buildings may become a veritable eyesore if these features of the landscape are sufficiently improved. A design may be in excellent taste, however, and yet be almost totally devoid of ornamentation. A few simple panels and copings are usually sufficient to lend an attractive appearance to masonry bridges, provided the planes of the wing walls, parapets, etc., are in proper relation to each other and to the roadway.

The accompanying photographs are intended to illustrate how an attractive appearance may be secured for culverts and small bridges at slight additional cost. (Pls. XIV, XV, and XVI.)

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